A PIT-Tag Based Investigation Into Somass River Adult Sockeye Migration Behaviour In Response To Environmental Conditions, 2010

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Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, BC
V9T 6N7

2015

Canadian Technical Report of Fisheries and Aquatic Sciences 3116

Fisheries and Oceans Canada
Pêches et Océans Canada

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

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Canadian Technical Report of
Fisheries and Aquatic Sciences 3116

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A PIT-TAG BASED INVESTIGATION INTO SOMASS RIVER ADULT SOCKEYE MIGRATION BEHAVIOUR IN RESPONSE TO ENVIRONMENTAL CONDITIONS, 2010

by

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Cat. No. Fs 97-6/3116E ISSN 1488-5379

Correct citation for this publication:

Pellett, K., Stiff, H.W., Damborg, J., and Hyatt, K.D. 2015. A PIT-tag based investigation into Somass River adult Sockeye migration behaviour in response to environmental conditions, 2010. Can. Tech. Rep. Fish. Aquat. Sci. 3116: vi + 173 p.

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ABSTRACT

Pellett, K., Stiff, H.W., Damborg, J., and Hyatt, K.D. 2015. A PIT-tag based investigation into Somass River adult Sockeye migration behaviour in response to environmental conditions, 2010. Can. Tech. Rep. Fish. Aquat. Sci. 3116: vi + 173 p.

A total of 2,809 adult Sockeye (*Oncorhynchus nerka*) were tagged with half-duplex Passive Integrated Transponder (23 x 3.85 mm HDX PIT) tags in Alberni Inlet and the Somass River between June 20 and August 15, 2010. Their migration behavior was monitored through the automated recovery of 893 tags at three antenna arrays located at Stamp Falls, Sproat Falls and Great Central Lake (GCL) fishways. Twenty-six additional tags were also recovered through commercial, recreational and First Nation fishery monitoring. Tag recovery rates were 28.6% for ocean-tagged and 35.2% for river-tagged Sockeye. Environmental variables monitored throughout the study included water temperature, barometric pressure, precipitation and river discharge (through stage height). Due to a consistently high level of fishery harvest in 2010, it was not possible to determine with any statistical certainty whether the stop, start, and duration of migratory events were strictly a function of changes in environmental conditions. Thus, focus was shifted solely to factors influencing migration rate.

Travel times for Sockeye tagged in-river at Papermill Dam (6.5 km upstream of the Somass mouth; n=1,322) averaged 3.4 ± 1.6 days to Stamp Falls (10.2 km upriver), 3.6 ± 1.6 days to Sproat Falls (5.9 km upriver) and 5.4 ± 1.9 days to the GCL fishway (23.7 km upriver). Sockeye tagged in Alberni Inlet (ocean-tagged; n=1,487) showed higher variability in migration time averaging 13.1 ± 7.0 days to Sproat Falls, 15.7 ± 7.5 days to Stamp Falls and 17.3 ± 7.1 days to GCL.

Sockeye took 2-3 times longer, on average, to swim the Sproat fishway than the Stamp fishway. The number of migrants was not an influential factor in fishway transit rate at observed population levels. Water temperature was negatively correlated with transit time in the Sproat fishway while water level was positively correlated with the speed of passage at both Stamp and Sproat fishways.

While these results do not specifically indicate causation, they implicate water temperatures in the lower Somass as the principal factor in Sockeye migration behaviours, with secondary and likely interaction effects related to water levels. However, environmental conditions in the Somass watershed were relatively moderate in 2010, and the results of this study may not apply to years of extreme conditions.

RÉSUMÉ

Pellett, K., Stiff, H.W., Damborg, J. et Hyatt, K.D. 2015. Étude de l'adaptation comportementale du saumon rouge adulte aux conditions environnementales de la rivière Somass par marquage au moyen d'étiquettes à transpondeur passif intégré (2010), rapp. tech. can. sci. halieut. aquat. 3116: vi + 173 p.

Au total, 2 809 saumons rouges adultes (*Oncorhynchus nerka*) ont été marqués au moyen d'étiquettes à transpondeur passif intégré dans le passage Alberni et la rivière Somass entre le 20 juin et le 15 août 2010. Leur comportement migratoire a été contrôlé grâce à la récupération automatisée de 893 étiquettes par trois réseaux d'antennes situés aux passes migratoires des chutes Stamp, des chutes Sproat et du lac Great Central. Vingt-six autres étiquettes ont été récupérées grâce à la surveillance des pêches commerciales et récréatives et des pêches des Premières Nations. Le taux de récupération des étiquettes a été de 28,6 % dans le cas des individus marqués en mer, et de 35,2 % pour les saumons rouges marqués en rivière. Les variables environnementales qui ont fait l'objet d'un suivi au cours de l'étude comprenaient notamment la température de l'eau, la pression barométrique, le taux de précipitation et le débit du cours d'eau (selon le niveau de l'eau). En raison d'un niveau constamment élevé de prises en 2010, il n'a pas été possible de déterminer avec certitude statistique si la fin, le début et la durée des épisodes migratoires étaient strictement attribuables aux changements dans les conditions environnementales. C'est pourquoi l'étude a été réorientée pour porter uniquement sur les facteurs influençant le taux de migration.

Les distances parcourues par le saumon rouge en rivière au barrage Papermill (6,5 km en amont de l'embouchure de la rivière Somass; n = 1 322) ont été établies en moyenne à 3,4 jours ± 1,6 jour à la passe migratoire des chutes Stamp (10,2 km en amont de la rivière), à 3,6 jours ± 1,6 jour à la passe migratoire des chutes Sproat (5,9 km en amont de la rivière) et à 5,4 jours ± 1,9 jour à la passe migratoire du lac Great Central (23,7 km en amont de la rivière). Le saumon rouge marqué au passage Alberni (marqué en mer; n = 1,487) indiquait une grande variabilité dans la durée de migration, soit une moyenne de 13,1 jours ± 7,0 jours aux chutes Sproat, de 15,7 jours ± 7,5 jours aux chutes Stamp, et de 17,3 jours ± 7,1 jours au lac Great Central.

Saumon rouge a eu 2-3x plus de temps, en moyenne, à nager la passe migratoire des chutes Sproat que le passe migratoire des chutes Stamp. Le nombre de saumons migrateurs ne semblait pas être un facteur déterminant dans la durée de transit au niveau des populations observées. Une corrélation négative a été établie entre la température de l'eau et la durée de transit à la passe migratoire des chutes Sproat, alors qu'une corrélation positive a été établie entre le niveau de l'eau et la vitesse de passage à la passe migratoire des chutes Stamp.

Les données ont été analysées par régression paramétrique et par fréquence des catégories. Bien que ces résultats n'indiquent pas précisément un lien de causalité, ils laissent tout de même entendre que la température de l'eau dans le cours inférieur de la rivière Somass serait le principal facteur influençant le comportement migratoire du saumon rouge, et qu'il pourrait y avoir des effets d'interaction secondaires liés aux différents niveaux d'eau. Les conditions environnementales dans le bassin hydrographique de la rivière Somass étaient toutefois relativement modérées en 2010. Il est donc possible que les résultats de la présente étude ne s'appliquent pas aux années de conditions extrêmes.

1. INTRODUCTION

Understanding the prevailing environmental conditions that affect Sockeye salmon migration behaviour in the Somass basin is a critical step in directing future habitat restoration and mitigation activities in relation to anticipated climate change. Water temperature, barometric pressure, and water quality conditions in upper Alberni Inlet have been identified as possible limiting factors (Hyatt, unpublished observations). High water temperatures during key migration periods may induce significant pre-spawn mortality. En route mortality has been documented in the lower reaches of the Somass River and Alberni Inlet (Stucchi et al.1990), while migration has stagnated during similar periods before resuming under cooler conditions (Birtwell and Korstrom 2002).

Timed hypolimnetic cold-water releases from one or more large upstream lakes have been identified as a potential climate change mitigation project for the Somass system. In advance of engineered mitigation efforts, key background data are required to describe the physical characteristics and fish population behaviors in the watershed.

Basic indicators of Sockeye migration behaviour include migration timing (e.g., number of fish per day passing a certain point), migration patterns (e.g., migration start and stop activities, indicated by significant changes in migration timing), migration rate (speed of travel for a specific distance), and survival/mortality.

Passive Integrated Transponder (PIT) tag and radio telemetry studies have been used elsewhere to investigate effects of environmental factors (mainly water temperature and flow) on migration behaviour (Boggs et al. 2004; Goniea et al. 2006), timing (English et al. 2004; Fryer et al. 2011, 2012, 2014; Goniea et al. 2006; Keefer et al. 2004; Smith et al. 2002), and fish survival (Connor and Yearsley 2003; English et al. 2004; Fryer et al. 2011, 2012, 2014; Martins et al. 2011, Smith et al. 2002). In these studies, travel speeds and survival are correlated with water flow levels (positive from low to moderate flows and negative with high flows), and inversely correlated with water temperature. For example, Fryer et al. (2011, 2012, 2014) measured decreased migration rates as flows increased and decreased survivals as temperatures increased during annual migrations for Columbia River Sockeye adults. Similarly, Goniea et al. (2006) measured decreased migration rates (average swim speed) and altered migratory behaviours for Columbia River Chinook adults at mean daily water temperatures exceeding 20°C; in such cases, the fish were found holding in tributary cool-water refugia more frequently.

Historical Sockeye migration studies (Hyatt et al. 2015) in the Somass watershed indicate that daily migrations of Sockeye during July and August of each year (1980-2007) were inversely correlated with Somass water temperature, discharge, and precipitation ($P < 0.01$). However, step-wise multi-variate regression analyses for weekly median stock-specific migration rates as a function of these four environmental variables retained only water temperature as a significant predictor at the $\alpha = 0.05$ level. Water temperature in the lower Somass accounted for 20-22% of the observed variation for Sproat and GCL, respectively, while the next largest contributor of explained variance, discharge levels, accounted for 1% or less of the variation, and was thus analytically excluded from the final models (Hyatt et al. 2015).

Although informative, the analysis of temperature impacts on historical Somass Sockeye migration was largely based on a reconstructed time-series for daily mean water temperatures. These were based on regional air temperature relationships with water temperature datasets (often intermittent and characterized by various levels of site-specific sampling bias) which could not effectively capture temperature extremes. The provision of a number of *in situ* data loggers installed by the British Columbia Conservation Foundation (BCCF) in 2009 and 2010 for continuous monitoring of environmental conditions in the Somass watershed, have provided higher quality data on diel and daily changes in water temperature, water levels and barometric pressure for the present study. In conjunction with a PIT tag program for monitoring individual and group fish movements, these data provide an opportunity to re-examine the relationship between Somass Sockeye migration behaviour and watershed environmental factors in more detail.

1.1. OBJECTIVES

The objectives of the current study were to:

1.1.1. Field Objectives

1. Install and deploy continuous water temperature, water stage height, and barometric pressure monitoring equipment.
2. Install antenna arrays at the three fishways that facilitate access by adult sockeye to Sproat and Great Central lakes within the Somass watershed.
3. Apply up to 3,000 uniquely coded PIT tags to adult Sockeye at two locations throughout the majority of the run on a weekly schedule.
4. Recover tags at antenna arrays or through fishery monitoring.
5. Maintain electronic tag recovery equipment and download data at regular intervals.

1.1.2. Analytical Objectives

1. Investigate the relationship between Sockeye migration behaviours and environmental conditions in the Somass watershed:
    a) Identify timing and duration of depressed/stagnant Sockeye migration periods.
    b) Correlate migration behaviour with environmental variables and define critical water temperature thresholds.
    c) Calculate migration time between tagging and recovery locations, as well as within the fishways, to update management assumptions regarding fish travel rates.
    d) Calculate en-route mortality rates and associate with environmental conditions.
2. Secondary objectives identified by DFO as opportunities to improve management information included:

a) Calculate weekly changes to Sockeye stock composition (Sproat vs Great Central) throughout the tagging period.

b) Calculate fishery harvest rates based on tag recoveries at landing locations.

1.2 STUDY AREA

The Somass River watershed (Figure 1) is the second largest on Vancouver Island, draining an area of 1,285 km^2 into the Pacific Ocean through Alberni Inlet and Barkley Sound (Morris and Leaney 1980). Two large lakes, Sproat and Great Central, moderate water levels for the system with surface areas of 44 km^2 and 52 km^2, respectively. The Somass River has a mean annual discharge of 122 m^3/s at its confluence with Alberni Inlet near the City of Port Alberni (Burt 1999). The Stamp and Sproat rivers form the Somass River approximately 3.5 km upstream of tidewater while the Ash River contributes approximately 35% of the flow to the Stamp River. Taylor River, the largest tributary to the Sproat drainage, flows into the west end of Sproat Lake (Figure 2).

Alberni Inlet is 40 km long and connects the Somass River to Barkley Sound. Several significant watersheds drain into the inlet, including: China, Cous, Franklin, Macktush, Nahmint, Henderson, and Coleman. The inlet supports significant sport and commercial salmon fisheries for a variety of species (e.g. Sockeye, Chinook, Coho, Chum salmon). The Sockeye fishery alone generates millions of dollars per year for the local economy (Gislason 2007) and represents significant cultural value to the local First Nations. The history of the fishery and Sockeye populations of the Henderson and Somass watersheds is described in Hyatt and Steer (1987). The construction of fishways[1] at Stamp Falls (1927, 1954) and Sproat Falls (1951), as well as decades of artificial nutrient enrichment of Great Central Lake (Hyatt et al. 2004), are considered of particular significance to trends in the production of sockeye salmon in the Somass watershed. For example, lake fertilization alone was attributed with increasing Sockeye harvest (LeBrasseur et al. 1979) from an average of 34,000 (1901-1960) to 350,000 (1980-2010).

Several barriers to fish migration exist throughout the watershed. Sproat Falls is located 550 m downstream of the outlet to Sproat Lake[2] and has been bypassed with a vertical slot-type fishway. Stamp Falls is located 6.2 km upstream of the Sproat confluence and is the site of a major fishway. A dam at the outlet of Great Central Lake was originally constructed in 1925 and modified in 1957 in an effort to store water for pulp mill effluent dilution (Hyatt and Steer 1987). The 1957 modifications included a new GCL fishway to maintain fish passage into the lake. The Ash River has several barriers including Lanternman, Dickson and Ash Island Falls as well as Elsie Lake Dam and thus is not a producer of Sockeye salmon[3]. No fishways have been constructed to date at these locations although some blasting at Dickson Falls has been conducted to facilitate steelhead passage (Burt 1999).

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[1] All fishway structures in the Somass system are designed as a repeating series of steps created via concrete compartments or cells, each 3 meters in length, connected by narrow vertical slots which permit fish passage. The Stamp Falls fishway cells are approximately twice as tall as the Sproat Falls fishway, with similar cell width and slope gradient.

[2] Sproat Lake water levels are passively controlled with a low-head weir at the outlet of Sproat Lake, which is connected by overland pipeline to Port Alberni to provide a reliable source of water for kraft pulp-mill operation.

[3] The relatively small surface area (Figure 2) and high flushing rates for lakes in the Ash watershed preclude significant Sockeye production.

The three fishways noted above are located at critical migration points within the Somass watershed. Sockeye enter the lower river bound for the two major headwater lakes, Great Central and Sproat that provide excellent holding conditions during summer in cold hypolimnetic depths prior to fall spawning. Great Central Lake is annually enriched via addition of inorganic nutrients by the Department of Fisheries and Oceans (DFO) to increase its productive capacity and boost Sockeye smolt output (Hyatt et al. 2004). Sproat Lake is not enriched (Hyatt et al. 2011). Submerged benches at 10-100 m depth represent key spawning habitat as Sockeye tend to prefer upwelling groundwater at these locations (Burt 1999).

The confined nature of the fishways also provides an ideal opportunity for fish enumeration and tagging activities. Consequently, the fishways (Figure 2) were chosen as sites to deploy antenna arrays to detect tagged Sockeye prior to their entry into the headwater lakes and their tributaries where all spawning activity occurs.

2. METHODS

2.1. PIT TAG TECHNOLOGY AND DATA

2.1.1. PIT Tag Application

Radio Frequency Identification (RFID) technology has been extensively used to monitor salmonids in the Columbia River basin since 1987 (www.ptagis.org). Each tag has a unique code that is relayed back to either monitoring equipment at antenna arrays or hand scanners via radio frequency. The tag is only activated while passing through the electromagnetic field generated at the antenna array (Figure 3) and remains dormant outside of the field. As there are no batteries associated with the tag, the lifespan is several times greater than that of the fish. The tags are produced on a large scale, costing under $3 each, two orders of magnitude less than radio telemetry tags. Tags used in this study were 23 mm long and 3.85 mm in diameter weighing 0.6 g (Figure 4). Half duplex (HDX) tags were selected, as they are less sensitive to interference than full duplex tags with a simplified antenna design.

All Sockeye tagged in this study were netted by purse seine or beach seine. Upon capture, tags were inserted into the ventral side of the abdominal cavity of each fish by using a specialized syringe with a 6 gauge needle (Figure 5). Tag positioning was exterior to the stomach (to minimize expulsion) in the anterior portion of the abdominal cavity in order to avoid the possibility of tag consumption if the fish was harvested in sport, commercial or First Nation fisheries. The adipose fin of each tagged Sockeye was also removed, as a secondary mark, in order to easily identify repeat captures and recoveries at landing sites. Fish were released immediately following tagging with few (<5%) exhibiting signs of handling stress.

Two primary capture and tagging locations (i.e. seaward entrance to Alberni Inlet and Papermill Dam in the lower Somass River) facilitated subsequent determination of migration rates and behaviour in marine and freshwater environments respectively. The number of tags applied in each location varied in proportion to forecasts of seasonal abundance variations, with the largest applications occurring near the peak of the run (June 28th in Alberni Inlet and July 13th in the lower Somass River (Figure 6).

Tags were scanned prior to application in order to record the unique 64-bit identifier (e.g. 0000_0000000174144264). Tag numbers were grouped by application date and location and entered into a spreadsheet. Biological traits measures (i.e. length, weight, sex, etc.) were not obtained for tagged individuals in order to reduce handling times and associated stress. Tag recoveries occurred through regular sampling of fisheries conducted by DFO at catch landing sites and during weekly test fishing operations throughout the season.

2.1.1.1. Ocean-Based Tagging Operations

Ocean tagging occurred aboard a commercial seine boat (the ARGENT 1) at several locations in Alberni Inlet and the inner portion of Barkley Sound (Figure 7). The seiner is routinely chartered by DFO as a test fishing vessel to obtain in-season stock assessment data. Test fishing occurred on a weekly basis throughout the majority of the Sockeye run. Sets were made with a commercial purse-seine net approximately 390 m long and 39 m deep. Fish were brailed out of the purse with a dip net operated by deck hands. Tags were applied in a specialized cradle and the fish were released directly overboard after receiving an adipose clip. A total of 1,487 tags were applied between June 14th and July 19th. The number of fish captured by the vessel exceeded the number of tags that were scheduled to be applied every tag session. Only larger, older Sockeye were tagged; jacks (i.e. smaller age 3 fish) were excluded from the study. Although exact times were not recorded for tagging operations on the ARGENT 1, DFO staff indicated the majority of tags were applied between 14:00 and 17:00 hrs.

2.1.1.2. River-Based Tagging Operations

Fish were also captured in the lower Somass River at Papermill Dam Park, approximately 6 km above the river's mouth in Alberni Inlet (Figure 2). A large pool immediately below the tidal boundary was fished with a 30 x 7 m beach seine until the target number of tags was applied (Figure 8). First Nations groups (Hupacasath and Tseshaht) fish the area with nets 50-65 m in length during food and ceremonial fisheries. Tagging efforts were focused on either, a sub-sample of fish from each First Nation's seine-set or on fish from a separate set after FN fisheries were complete. When fisheries were not underway, one to three band members assisted BCCF staff with fish capture. A minimum crew of six was required to operate the smaller beach seine while up to fifteen were required for the larger net. Both nets were loaded into a boat and set across the direction of flow upstream of the fish. Crew members pulled the shore end of the net downstream along the river-bank while the boat (with 2-3 crew members) towed the outside end of the net downstream towards the tail-out of the pool. All crew would pull the net to purse the fish into the shallows to allow their capture with a dip-net. Sockeye were dip-netted, one to five fish at a time and transported into a holding tank. The tank was constructed from a commercial fish tote and held approximately 600 L of water. A continuous supply of fresh water was delivered through a 2" fire pump into the tank to sustain oxygen levels and constant water temperature.

A total of 1,322 Sockeye were PIT tagged at Papermill Dam pool on the lower Somass River from June 28th to August 11th.[4] Although tag application targets were set based on run timing, the actual number of tags applied was often limited by low catch numbers; consequently, jacks were tagged as well as adults.

Fish were released back into the pool immediately following tagging. The majority were observed to hold for a few minutes in shallow water before migrating into the deeper portion of the pool. Those released in faster water tended to hold longer or move downstream. Less than 5% of fish showed signs of stress, including rapid opercular movement, improper orientation, or stranding in shallow water.

Environmental conditions, including daily mean water temperature for the Somass and Sproat rivers, barometric pressure, and ambient air temperature at the time of tagging were recorded. Daily mean water temperatures in the Somass River during tagging operations were 15-17°C in early July but were considered to be super-optimal thereafter as temperatures exceeded 18°C (Table 1). No tags were applied in-river during the week of July 26th to August 1st due to concerns related to the impact of persistent high water temperatures on survival.

2.1.2. PIT Tag Detection / Recovery

Tag detection arrays were installed at each of the three fishways between May 20 and June 4, 2010. The arrays at Stamp and Sproat falls were similar with two antennas (Figure 3) located 18 m apart (at the 62- and 80-meter points) in the 90-meter long Stamp fishway, and 27 m apart (at the 10- and 37-meter points) in the 43-meter long Sproat fishway, with the uppermost antenna located near the exit (Figure 9). Logistical challenges at the Great Central Lake (GCL) site resulted in a single antenna array located at the exit of fishway where fish enter the lake.

Antennas were constructed using 12 AWG single conductor multi strand copper wire looped 2-3 times inside of ¾" schedule 40 PVC conduit. The dimensions of each antenna varied depending on the orifice size between the chambers of the fishway (Figure 3). Antennas were anchored to the concrete using ¼" x 3" stainless steel wedge anchors, nylon lock nuts, and metal conduit strapping. The antenna was positioned on the downstream side of each orifice for protection against turbulence and debris. The tuning box was installed as close to the antenna as possible but far enough above the water surface to avoid immersion during high flows. Longer lengths of 100 ohm twin-axial shielded data cable connected the tuning boxes at each antenna to the OREGON RFID reader, which was housed with the battery bank in a metal container.

Three 150 aH, 12V deep-cycle, lead acid batteries were connected in parallel to power the RFID readers at the Sproat and Stamp Falls arrays (Figure 10). Batteries were recharged on a weekly schedule in order to keep the reader operating at the recommended voltage. The array at Great Central Lake was powered through a converter plugged into a 120V AC power outlet at the Catalyst Dam. The flow within the GCL fishway could not be shut off, so antennas could not be installed on the orifices. Instead, a single antenna was fixed to the upstream side of a set of PULSAR™ electronic counting tunnels installed earlier by DFO (Figure 11).

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[4] A total of five fish were tagged and released downstream of the Sproat Fishway to test the Sproat detection antenna on June 1st.

Radio frequency identification (RFID) readers at each antenna array were configured using a personal digital assistant (PDA) connected via serial cable. This allowed for adjustment of charge/listen cycles, antenna sequencing, labelling reader ID, and data retrieval. The reader was programmed to continuously monitor the Stamp and Sproat arrays at a rate of 7 scans per second at each antenna. As only one antenna was used at the GCL array, the scan rate was increased to 14 per second. Except for brief intermittent interruptions for routine maintenance, the RFID readers at each antenna array operated continuously for the duration of the project, recording the date, time, and ID number for passing tags to an internal memory card. The memory cards were downloaded weekly for cross-linking with tag application data.

2.2. FISH MIGRATION DATA

Sockeye catch and escapement estimates were obtained from DFO in order to calculate weekly harvest rates and assess the level of impact of fisheries on upstream migratory patterns (D. Dobson and J. Till, DFO Nanaimo, 01-Apr-11, unpub. data). Escapement data were also aligned with tag detection tallies by stock and date to develop a predictive relationship for stock migrant populations as a function of the number of tags. Weekly harvest rates were calculated as the percentage of the weekly harvest across all gear types, areas, and fisheries (commercial, recreational, and FSC) divided by the total weekly catch plus escapement of adult and jack Sockeye.

To perform the harvest rate calculation, total weekly returns were estimated based on weekly total harvest and escapement data as follows. Daily stock-specific escapement totals were lagged back in time to a common location (Alberni Harbour) from their respective counting facilities based on observed migration rates for fish tagged at Papermill Dam, and summed by week across stocks. Similarly, weekly harvest totals were lagged forward in time (as if they had not been caught) from the harvest location to Alberni Harbour, assuming a constant travel speed of 5.7 km/d in marine waters (Manzer et al. 1985). Total weekly returns were estimated as the sum of weekly catch plus escapement. The sources of these data are described in some detail below (sections *2.2.1. Sockeye Escapement Data* and *2.2.2. Sockeye Harvest Data*).

Although these harvest rates represent only a coarse estimate of the impacts of fishing effort on the numbers of fish arriving at the Somass Estuary, they can be used to roughly categorize Sockeye migration patterns (and evident start and stop migration events) as: *not impacted* by fisheries (i.e., zero harvest by any fishery for Sockeye arriving at the Somass during that week), *potentially impacted* (i.e., total weekly harvest rate greater than zero but less than 25%), and *significantly impacted* (i.e., total weekly harvest rate greater than 25%). Migratory stop/start events associated with harvest rates greater than 25% were deemed confounded by fishery impacts and omitted from analyses relating migratory events to environmental variables alone.

2.2.1. Sockeye Escapement Data

Enumeration of Sockeye migrants occurred at Sproat and Great Central Lake fishways for the duration of the experiment. Fish counting operations on the Somass system are conducted by the Hupacasath First Nation in collaboration with DFO. To estimate the escapement of Somass Sockeye, automatic PULSAR™ fish counters were installed at the Sproat and Great Central fishways in mid-May. The counters are based on resistivity technology and use a series of copper bands inside of plexi-glass tunnels to monitor upstream and downstream migration. Twice weekly visual calibrations are used to validate counter data as well as to determine species and age composition (i.e., jacks versus larger adult salmon) of escapement. A portion of the Sockeye escapement is also sampled weekly for biological traits at the fishways. Automated fish counters are removed from the Stamp River fishway in early September when Chinook begin to migrate upstream. All Sockeye, Chinook, and Coho salmon passing through the Stamp Falls fishway after the PULSAR counter is removed are enumerated by trained observers to identify fish species, jack proportion by relative size, and proportion of marked (adipose fin clipped) fish. Migration through the fishway is videotaped for later verification of diurnal real-time counts, species composition, and night-time migrants. Real-time observations are typically greater than 95% accurate for counts, species identification, and mark rate (Jeff Till, Coordinator, Somass Indicator Program, pers. comm.).

2.2.2. Sockeye Harvest Data

Weekly harvest totals for Barkley Sound fisheries were provided by Fisheries and Oceans Canada (D. Dobson, DFO, pers. comm.). These data include weekly summaries by gear, for: commercial gillnet, seine, and troll (catch estimates from hails for seine and gillnet gear or troll logbooks); recreational rod and reel (creel sampling for sport catch), First Nations gillnet and seine for social, food and sale fisheries (SFSF); gillnet and seine test-fishery landings for research and fisheries management (direct enumeration).

Catch and effort information in this dataset is generally limited to statistical week ("stat-week") harvest totals by fishery and gear type for: (1) "Inside" waters, meaning sub-areas 23-1 and 23-2 within Alberni Inlet (Figure 9) or: (2) "Outside" waters, referring to sub-areas 23-3 at the entrance to Alberni Inlet seaward to 23-7 in Barkley Sound.

Given Sockeye travel rates of 5.7 km/d in saltwater (Manzer et al. 1985), the number of days required for fish to travel from fishery locations (had they not been caught) to the Somass estuary were assumed (Labelle and O'Brien, unpub.) to involve: 2 days travel through each of "Outside" sub-areas 23-7 to 23-3), and 3 days for each of the "Inside" sub-areas (23-2 and 23-1) to the head of Alberni Inlet.

For example, recreational fisheries occur mainly in sub-areas 23-1 and 23-2, with a concentration of effort from Stamp Narrows to the Nahmint River mouth, in 23-2 (Labelle and O'Brien, unpub.). Thus, it may be assumed that Sockeye taken by sport fishermen would have arrived at the Somass estuary about 3 to 4 days later if they had not been caught.

Although commercial fishery catch and effort cannot be assigned with certainty to sub-area due to the historical aggregation of harvest data over multiple locations by statistical week, commercial gillnet fisheries have typically concentrated in the "Outside" waters in sub-areas 23-3 and 23-4 over the past decade (Labelle and O'Brien, unpub.). Thus, it may be assumed that Sockeye that were caught in the "Outside" commercial gillnet fishery were largely part of the same group of fish that arrived at the mouth of the Somass 8 - 10 days later.

The lagged harvest data from different fisheries occurring at different times were summed across fisheries by week-ending date of arrival at the Somass estuary (had the fish not been caught) to estimate the total weekly exploitation rate (%) as a function of the total Somass run size (GCL and Sproat stocks combined)[5]. The aggregated weekly exploitation rate was extrapolated from the week-ending date of arrival, to the previous six days of the corresponding stat-week.

2.2.3. PIT Tag Migration Data

Assembled data were summarized and statistically analyzed using SAS® software. Tag codes occurring in the detection data with no match in the tagging operations data were considered transcription errors and omitted from all analyses. Valid tag detection data were filtered for first and last detection records at each detection site and antenna to determine net passage times across each antenna and between antennas (i.e., net fishway passage time). Time of last detection at the last antenna at each detection location was used as a measure of the date and time of passage at that site for purposes of calculating travel time (in days).

Tag detection failure rates were estimated for each fishway with multiple antennas by comparison of tag identification numbers at each antenna. A tag recorded at the upstream antenna but undetected at the lower antenna was considered a tag detection failure event if a review of the data indicated no concurrent operational interruptions (e.g., manual battery changes) that might account for the missed detection.

PIT tag recovery data (tag RFID, date, location) from other sources (fisheries) obtained from DFO and First Nations were matched with tag application data and collated in a Microsoft Excel® worksheet.

During seasonal intervals, absent significant harvest activities, changes in population migration patterns revealed by daily PIT detections may be attributed to environmental conditions alone. Observations from ocean-tagged fish were used for this analysis, since these tags are more mixed by the time they reached the inner harbour area, while river-tagged releases would be characterized by a strong weekly pulse of released fish. To test that the ocean tag data were representative of the population of migrants, the daily ocean tag counts from each detection site were lagged back to a common location (Somass Harbour), summed, and correlated with escapement totals (GCL + Sproat, adults + jacks), which were also lagged back in time from their respective counter sites. Strong correlation between the tag data and counter data would support the hypothesis that the two datasets are from the same population, and serve as corroboration for apparent migration behaviour events, which could then be correlated to environmental conditions in the absence of fishery impacts.

2.3. ENVIRONMENTAL DATA

2.3.1. Water Temperature

Water temperatures were monitored continuously during the study period at seven locations throughout the Somass watershed (Table 2). ONSET® HOBO® WATER TEMP PRO v2 temperature loggers, accurate to ±0.2°C between 0°C and 50°C, were deployed in the Somass, Stamp, Sproat, and Ash Rivers. Loggers were secured using a 3.2 mm stainless steel cable tethered either to bedrock using a ¼" wedge anchor, or around a nearby tree or other solid structure. Depending on site characteristics, loggers were placed 0.5 - 1.5m beneath the surface, near the river bottom. Loggers were synchronized to record temperatures every 15 minutes, on the quarter hour. Daily mean water temperatures (MWT) were derived from data logger source data where sampling was representative of the entire 24-hour period.

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[5] Total annual Somass run size (catch + escapement), total Barkley Sound catch, and the resulting total annual exploitation rate were supplied by DFO (D.Dobson, DFO, pers. comm.).

2.3.2. Water Level

Stage height was determined with the deployment of pressure transducers (SOLINST LEVELOGGER® GOLD MODEL 3001 – LT F15/M5*)* installed at three historic but inactive Water Survey Canada (WSC) gauging sites. The first logger was installed in the Ash River, near the confluence with Moran Creek (08HB023), another in the upper Stamp River downstream of the Robertson Creek Hatchery (08HB009)[6], and one in the lower Somass River, near Somass Park (08HB017). Sensors were hung off the bottom using a 3.2 mm stainless steel cable. Water level over the sensor was measured at the time of deployment to ensure functionality of the instrument. Loggers were set to record every 15 minutes on the quarter hour, producing continuous level data at these three locations. Daily mean water levels (MWL) were derived from data logger source data where sampling was representative of the entire 24-hour period.

Sproat Lake daily mean water level data, recorded hourly at the Catalyst intake pipe in Taylor Arm (unpub. data, Larry Cross, CATALYST (Alberni) Ltd., May 2011), were used as a proxy for Sproat River water level data, which were unavailable from the WSC website at the time of this report.

2.3.3. Barometric Pressure

Barometric pressure data were collected using a SOLINST BAROLOGGER GOLD MODEL *3001* (specifications: full scale (FS) - 4.92 ft., 1.5 m, accuracy ± 0.003 ft., 0.1 cm, resolution 0.002%) deployed on June 28th, 2010, adjacent to the LEVELOGGER near Robertson Creek Hatchery. Barometric pressure was recorded every 15 minutes on the quarter hour. Measurements were recorded in water height equivalents (m) to be used as a correction factor for the water height indicated by LEVELOGGERS. Daily mean barometric pressure (BP) was derived from data logger source data where sampling was representative of the entire 24-hour period.

2.3.4. Air Temperature and Precipitation

Regional air temperature and precipitation data were downloaded from the Environment Canada website[7]. Mean daily air temperatures and total daily precipitation were obtained for Robertson Creek, Station 1030230. Daily mean air temperature data were converted to 10-day centered moving averages, which correlate most strongly with daily mean water temperatures in the Somass system (Hyatt et al. 2015). Missing daily mean air temperatures for periods less than or equal to three days were interpolated. Missing precipitation data (June 14, July 5-6, 15, 23, August 19, 20, 28, 29, September 12, and October 17, 24) were not interpolated or estimated; precipitation for missing dates from

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[6] At the site of the inactive WSC hydrometric station.

[7] National Climate Data and Information Archive (April 2011) http://climate.weatheroffice.gc.ca/climateData/canada_e.html

June through September was assumed negligible due to zero amounts of rain for immediately preceding and subsequent dates.

2.4. DATA ANALYSIS

2.4.1. Environmental Variables

Univariate statistical analyses were used to determine central tendency (mean, median, and mode) and scale (range, standard deviation) statistics, and to detect outliers for the above environmental variables. Kolmogorov-Smirnoff and Anderson-Darling tests were used to determine whether the variables met normality assumptions. Logarithmic and/or root-four transformations were applied where appropriate in an attempt to normalize data for parametric statistical analyses. For variables characterized by relatively small variance in relation to the large values (e.g., Sproat Lake water level), the data were standardized to a mean of zero and standard deviation of one.

A number of lagged and/or multi-day mean variates were formulated from the daily mean values of the environmental variables to represent approximate "periods of exposure", based on logical assumptions governing travel time in specific components of the freshwater environment. These included multi-day backward moving averages for 2- to 7-day periods, lagged back in time from 0 to 3 days, which were merged with individual tag data (tag ID, tagging location, travel time, travel rate, etc., described below) based on date of tag detection. Backward moving averages were most useful since the physical and temporal location of tagged fish could best be approximated using the date and location of tag detection data in combination with mean travel rates. Although the date of entry into the Somass of river-tagged fish could be easily approximated based on available tagging date information, the date of entry into the freshwater environment of ocean-tagged fish was unknown, nor was the exact date of entry into the Sproat or Stamp Rivers available for either river- or ocean-tagged fish under this experimental design. Thus, exposure to environmental conditions in locations and daily intervals immediately prior to detection were considered to be of highest relevance to associated behaviour of either Sproat or GCL-bound fish.

The assumptions used in developing these "exposure period" variates were based on empirically-derived median and quartile tag travel times from Papermill Dam to the detection sites, which indicated that 95% of fish reached Stamp and Sproat fishways within 3-5 days after leaving Papermill Dam, and reached the GCL fishway within 5-7 days. The travelling speed of most fish was therefore about 3.5 to 5 km/day. Given the location of Papermill Dam 6.8 km from the mouth of the Somass, an additional two days of exposure time to environmental variables such as Somass water temperatures was considered reasonable. Since water temperature and water level conditions in the Sproat River system and upper Stamp were considerably different than the Somass component, a combination of exposure variates corresponding to detection site conditions for periods of 0 to 3 days immediately preceding the tag detection date, plus Somass conditions for periods of 0 to 3 days lagged 2-3 days earlier, were assembled for analysis with tag data.

All variates were subsequently analyzed for auto-correlation (time-trends). Since, for most environmental variables, significant auto-correlation effects were damped out within 1-3 days, weekly statistics (means, medians, maxima) were calculated for use in parametric statistical analyses.

Parametric and non-parametric cross-correlation analyses were performed to examine inter-relations among environmental variables, based on Pearson and Spearman rank correlation coefficients, respectively.

2.4.2. Antenna Efficiency

Efficiency of the Sproat and Stamp arrays was determined by comparing individual tag detections at the upper and lower antennas[8]. Since not all salmon that enter the fishway successfully ascend the structure, failed detections occurring only at the upper antenna were not included in antenna efficiency analyses. However, tags undetected only at the lower antenna were tallied as failed detection events. Tag detection efficiency (%) at each of the Sproat and Stamp (STP) fishways was then calculated as the ratio of failed detection events to the total number of tags detected at both antennas. Efficiency of the GCL array was not assessed as only a single antenna was installed. A comparison of GCL and STP detections was completed as a minimum measure of efficiency while recognizing en-route mortality may also have been a factor given the distance of several km between these two locations.

2.4.3. Tag Loss and Mortality

The insertion of tags into the abdominal cavity is suspected to result in a higher rate of tag loss compared to other body locations, such as the dorsal sinus where tag retention can be 100% (Dare 2003). While tag loss and tag-induced mortality were not investigated for either the river or ocean tagging operations, tag application at each location was conducted by the same personnel over the course of the project to ensure consistency between application dates.

2.4.4. PIT Tag Recovery Rate

The number of tags detected at each of the three arrays or recovered from a fishery was compared to the number of tags applied. Recovery rates were determined for each tagging date and at each tagging location. Arrays were active through to October 1 under the assumption the majority of active tags (live fish) would have entered the system 51-63 days after the final tagging sessions at PAPERMILL DAM and ARGENT 1, respectively.

Estimation of migrant bypass rates for each fishway location is well-documented by DFO personnel and taken into consideration when estimating tag recovery rates (Appendix Table III).

It was anticipated that a number of tags applied aboard the ARGENT 1 would be recovered during fish capture at PAPERMILL DAM (PMD), which would assist in describing marine travel rates. Tag recoveries from commercial, recreational, and First Nations fisheries were also investigated.

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[8] Troffe et al. (2010) reported a detection efficiency of 98.5% for chum salmon migrating through a similar sized array with failed detections occurring during times the equipment was without power. Consequently, missed detection events during battery changes or power failures were omitted.

2.4.5. Tag Travel Time and Travel Rate

Length of time between tagging and detection was calculated for each tag detection record to:

1. Test assumptions currently used in fisheries management regarding mean Sockeye migration rates in marine and freshwater environments; and
2. Provide a dependent variate to test the null hypothesis that environmental variables do not affect Somass Sockeye migration behaviour.

Individual tag travel time (days) between tagging locations and detection sites was calculated as the difference between the date of detection and date of tagging. A more precise calculation utilized the exact date-time of detection (obtained from RFID records) minus the date and approximate time of tagging operations (exact time of tagging was not recorded). Based on field crew notes regarding daily routines for tagging operations, all ocean-tagging operations were assigned a time of 5:00 pm; all river-tagging operations were assigned a time of 12:00 noon.

Univariate statistical analyses were used to determine relevant central tendency and scale statistics, including minimum, mean, maximum, median, and modal travel times by tagging location and detection location. The 95% quantile was used to identify and exclude outliers; this provided an upper limit of 12 days to any detection site as the cut-off for maximum travel times subsequent to in-river tagging, and an upper limit of 36 days as the cut-off for maximum travel times subsequent to ocean-based tagging.

Distances (km) between tagging locations and detection sites and other key locations in the Somass watershed were determined from topographic maps (Table 3). Travel rate or speed (km/d) for each tag[9] was then calculated based on the distance travelled and the travel time duration. Travel speed was used as a dependent variable in various statistical analyses since simple linear transformation of the travel time duration variable provides an inter-site comparable migration rate variable**, which** takes into account the relative distances involved.

Non-parametric analysis of variance was used to contrast the differences in mean swimming speed due to:

1. tagging location (ocean- versus river-tagged), by detection site;
2. ocean tagging location (Pill Point, Chup Point, Coyote Bluff, and Pocahontas Point), by detection site;
3. detection site (Stamp, GCL, or Sproat fishways), by tagging location; and
4. tagging date, by tagging location and detection site.

2.4.6. Travel Time as a Function of Environmental Variables

Since, for a given environmental data type (e.g., Somass water temperatures), the various exposure period variates (e.g., multi-day moving averages, lagged moving averages) are not independent, parametric and non-parametric correlation analyses between environmental variables and measures of migration rate were used to identify the most significant indicators for each environmental data type, by tagging location, and detection site or stock. The key correlates for each environmental data type were incorporated as predictors into parametric multiple regression models for migration rate as the response variable, again, by tagging location, and detection site or stock.

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[9] Since the duration between tag release and detection may be characterized by an unknown number of pauses in migration, travel speed should not be confused with fish swimming speed.

Standard, ordinary least squares (OLS) step-wise regression analyses were used (SAS 2009, GLMSELECT procedure) to identify the environmental variates that contributed most to the explained variance based on partial r^2 estimates for main effects and interaction effects. However, the OLS step-wise regression procedure, though widely used in statistical analyses, is known for over-fitting variates to the data, resulting in overly optimistic explanations of model variance, biased parameter estimates, and erroneous confidence intervals (Flom and Cassell 2007). A data reduction technique robust to low data independence (the least-angle-regression (LAR) technique[10] (Efron et al. 2004) was used to narrow the number of explanatory variables and reduce over-fitting of the regression model (Flom and Cassell 2007).[11]

Thus, to distinguish the relative importance or influence of the various correlated factors on Sockeye migration behaviour, predictive multi-variate models were developed based first on exploratory OLS step-wise regression techniques to detect a maximum of one variable from each environmental data type (e.g., Somass water temperature, Stamp water level, Sproat water temperature, precipitation, etc.), followed by LAR step-wise regression modeling to reduce over-fitting of the selected variates. The coefficient of variation (CV), based on the partial r^2 contribution of the variates to the LAR model, was used to define the level of explained variance attributable to any retained environmental effect.

Key environmental variates were also incorporated into stock-specific categorical factor models, based on contingency tables (binned frequency counts) of the environmental predictor variables and migration rate response variable. Environmental data were categorized based on partitioning of the daily and multi-day mean data into relatively equal percentiles (e.g., high, medium, low water levels), or according to empirical thresholds (e.g., above and below the 20°C water temperature level considered to be a barrier to Sockeye migration in historical analyses (Hyatt et al. 2015). Analysis of means (ANOM) procedures was used to identify and graphically portray environmental variate categories for which the continuous response variable differed significantly from the overall mean migration rate.

Tag data were categorized into simple high-medium-low “travel speed” bins based on partitioning the migration rate data into approximately equal percentiles. Multiple correspondence analysis (MCA) was applied to the resulting contingency tables to graphically examine associations amongst all factors combined. Mantel-Haenszel chi-square tests were used to test the null hypothesis that ordinal tag migration rate categories were not associated with ordinal environmental variate categories in two-way frequency analyses. Somers’ D (C|R) statistics were then computed to describe the degree of association, if any, between the row and column variables of the contingency table (SAS 2009).

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[10] The LAR step-wise method standardizes all variables, sets initial parameters to zero, and then adds variates and corresponding parameter estimates to the model based on correlations with the current set of model residuals (Flom and Cassell 2007).

[11] The robust LASSO (least-absolute-shrinkage-and-selection-operator) selection method (Flom and Cassell 2007) provided equivalent statistical results to the LAR (least-angle-regression) method.

Environmental factors that exhibited strong associations with the response factor were selected for a stratified (three-way) frequency analysis of the relationship between a primary environmental factor (row variable) and the migration rate response factor (column variable), after controlling for the potentially confounding levels in the secondary environmental factor (stratum variable). Cochran-Mantel-Haenszel (CMH) statistics were computed to test the null hypothesis of no association between columns and rows within strata against different alternative hypotheses (SAS 2009):

1. a general association exists between row and column variables, for at least one stratum of the second environmental variable;
2. a difference in row mean scores exists, for at least one stratum; or
3. a linear association (correlation) between row and column variables exists, for at least one stratum.

Significant results for any of the CMH tests[12] would indicate the associations between response and primary environmental variates exist, after adjusting for the secondary environmental variate. Alternatively, the primary and secondary environmental variables are likely non-independent and potentially interacting.

2.4.7. Swim Speed and Delays in Fishways

At the Stamp and Sproat fishways[13], several indicators of fishway transit timing were calculated for each tag detection to test for differences in transit velocity (or swim speed, in meters per minute) and delays under different seasonal and environmental conditions.

Swim speed was estimated from the difference in time of detection at each antenna divided by the distance between antennas, for records with only one tag detection at each antenna (to omit confounding multi-detections). Fall-back activity was examined based on records for which fish were detected multiple times at either antenna, but only once at the other antenna (omitting records where fish fell back below the fishway multiple times over the course of multiple hours or days). The frequency of such occurrences, antenna transit time (minutes), and associated inter-antenna swim speeds were summarized using Spearman ranked correlation analyses, non-parametric analyses of variance, and LAR-type step-wise regression analyses to:

1. compare Stamp versus Sproat fishway sites;
2. compare temporal (weekly) differences within and between sites;
3. test for a ‘crowding effect’ associated with the numbers of concurrent upstream migrants; and

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[12] The CMH statistics have low power for detecting an association in which the patterns of association for some of the strata are in the opposite direction of the patterns displayed by other strata. Thus, a non-significant CMH statistic suggests either that there is no association or that no pattern of association has enough strength or consistency to dominate any other pattern (SAS 2009).

[13] Only one antenna was installed at the GCL fishway, so transit velocities at the GCL fishway were not performed.

4. identify key independent environmental factors (water temperature, water level, barometric pressure, precipitation) associated with transit velocity variability.

For 'crowding effect' analyses, daily total GCL up-counts (net) tallied at the GCL fishway were lagged backward in time by two days to align with Stamp fishway tag detections. For Sproat-bound fish, hourly match-ups were also analyzed since the tag detection and counter sites were coterminous. Dates with more than two interpolated hourly counts resulting from electronic counter malfunctions were omitted from the analysis.

2.4.8. Stock Composition

Weekly stock composition was approximated for ocean-tagged fish by lagging date-specific tag detections at Stamp and Sproat antenna back in time by the modal travel time (in days) between Papermill Dam and the detection locations (i.e., 3 days for both Sproat and Stamp). For river-based tagging operations, the date of tagging was used. Ocean- and river-tagged datasets were then merged by date of passage at the Papermill Dam to estimate relative stock composition by date, week, and month based on all tag detections. The stock composition of the tagged dataset was statistically compared to the stock composition derived from estimated upstream migrant counts based on PULSAR electronic counters, appropriately lagged back to the Papermill Dam (i.e., 3 days for Sproat fish and 5 days for Great Central migrants) and merged by date. This analysis assumes equivalent tag-mortality rates between stocks and tag-detection efficiencies at the detection antennas.

2.4.9. Migration Stop/Restart Events

Stock-specific escapement time-series, lagged back in time to the Somass Papermill site, were analyzed for the presence of *active migration periods* (AMPs) within the *annual migration interval* (AMI). The parameters used to define and characterize the AMPs were obtained from a subjective visual analysis of historical annual migration timing data plots (Hyatt, unpub.data), and are defined as follows:

- The AMI constitutes the effective interval of sockeye migration for the stock. The AMI is defined as the period within the calendar year beginning on the Julian day on which cumulative daily sockeye migration exceeds 5% of the total annual escapement for that stock, and ends on Julian day 270 (approximately Oct. 1st).
- AMPs are arbitrarily defined as any multi-day period within the AMI for which the start date is characterized by a daily sockeye migration rate exceeding 2% of the annual stock escapement for one day, or 0.75% for a minimum of 3 days.
- AMPs are separated by *base periods* (BP), defined as intervals during which daily migration does not exceed 0.75% for a minimum of 3 days.
- The first date of an AMP after a BP is considered a *migration restart event* (MRE); the last date of an AMP before a BP is a *migration stop event* (MSE).

3. RESULTS

3.1 ENVIRONMENTAL MONITORING

3.1.1. Air and Water Temperature

Although the year 2010 was classified as a "warm" PDO and ENSO year in the North Pacific (CLIMATE IMPACTS GROUP [CIG] 2011[14]), typically characterized by warm, dry summer weather, local temperature conditions in the Somass watershed were closer to long-term norms[15]. Air temperatures during peak Sockeye migration timing (July-August) in 2010 averaged 19-20°C, slightly exceeding long-term averages, but well within climate variability norms, after a spring characterized by below-average temperatures through late May and early June (Figure 12). Air temperatures peaked in mid-August (as is generally the case) above 25°C for a few days, then returned to cooler temperatures (15-20°C) for the rest of the month, followed by an increase in variability in September associated with the onset of fall precipitation.

Consequently, daily mean water temperatures remained slightly lower than average in the early summer months in the Somass River (mean 19.2°C, max 22.4°C), and in the Stamp River (mean 18.8°C, max 22.2°C). Not until the latter half of August did water temperatures in the Stamp/Somass system exceed 20°C for any length of time (Figure 12). However, water temperatures in the Sproat River surpassed 20°C in early July, and remained there until the end of August, averaging 21.6 ± 1.4°C (range 18.2 – 23.9°C) (Figure 12). Maximum water temperatures coincided with a decrease in Somass Sockeye migration activity from late July to late August[16], and, as temperatures decreased in early September, a resumption in significant migration rates (Figure 13). Modal mean daily water temperatures were 19.0°C in the upper Stamp, 19.5°C in the Somass, and 22.5°C in the Sproat system (Figure 14).

3.1.2. Precipitation and Water Levels

The temperature drop in late May and early June mentioned above was characterized by frequent spring rains of 5-20 mm per day at Robertson Creek, but during July and August, daily precipitation totals dropped to an average of about 0.5 mm, less than half the long-term norms, with a daily maximum of 11 mm falling around August 7th which interrupted the dry spell that (Figure 12) but did not significantly increase river flows (Figure 15). Intermittent precipitation events beginning in late August were coincident with a drop in water temperatures, notably bringing Sproat temperatures below 20°C by August 29th. Total rainfall returned to average to above-average levels in September 2010.

Daily water levels for the Stamp and Sproat systems in 2010 largely reflected the regional rainfall pattern of spring freshets and fall storms.[17] Sproat River discharge

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[14] CLIMATE IMPACTS GROUP ocean climate classifications for the Pacific Decadal Oscillation (PDO) and El Niño Southern Oscillation (ENSO) patterns can be found at http://cses.washington.edu/cig/pnwc/compensopdo.shtml.

[15] Based on ENVIRONMENT CANADA Station 1030230 (Robertson Creek) Climate Normals for 1971-2000, at http://climate.weatheroffice.gc.ca/climate_normals/results_e.html?stnID=225&prov=&lang=e&dCode=1&dispBack=1&StationName=robertson_creek&SearchType=Contains&province=ALL&provBut=&month1=0&month2=12.

[16] However, this period was also associated with peak harvest rates in the commercial fishery (see Figure 31).

[17] Great Central Lake levels and flows into the Stamp River are actively managed at the GCL outlet, while Sproat Lake water levels are passively controlled with a low-head weir at the outlet of Sproat Lake (Hyatt et al. 2015).

(Figure 15), which approximated the long-term average[18] in June and September, fell to 12.8 and 4.0 cms in July and August relative to the long-term means of 16.4 and 7.8 cms (Appendix Table I)[19,20], reflecting reduced precipitation levels in the mid-summer months. Daily flows dropped below 2.0 cms for the first 10 days of August 2010 (*cf.*, lowest daily flow recorded: 0.67 cms, August 1998).

Stamp River data logger water level readings displayed considerably more variation over the period of study than Sproat levels[21], including an anomalous dip in water levels during peak Sockeye migration in early July, unrelated to precipitation patterns (Figure 16). The flux was due to GCL water retention and release activities at the GCL dam. On July 1, three stop logs were added to the GCL dam to meet the target constraint of the water licence for maintaining the lake at full storage (8-8.5 feet) to ensure water is available in late summer to maintain Stamp River flow at 3.5 feet or more (Larry Cross, CATALYST PAPER, pers. comm.). Sockeye migration activity appeared to be uninfluenced by the flux in water levels in this range (Figure 18). Water levels in Stamp River dropped steadily thereafter, unaffected by the brief precipitation event in early August (largely captured behind the dam), until late summer rains began on August 29th (Figure 18).

3.1.4. Barometric Pressure

Barometric pressure readings collected from a SOLINST BAROLOGGER displayed a general downward trend from mid-June to mid-September characterized by strong fluctuations (Figure 17). Peak readings occurred in the third week of July in the middle of the dry spell; the extreme low around September 19th was associated with the onset of autumn rains.

3.1.5. Covariance in Environmental Variates

Daily means of environmental variates were standardized to a mean of zero, variance of 1 to share the same y-axis, and plotted with standardized total daily Somass Sockeye escapement estimates (lagged back 2 days from Sproat and 4 days from GCL fishways) to visually review the temporal co-variability amongst variables (Figure 17).

Both parametric (Pearson) and non-parametric (Spearman) correlations (Table 4) suggest a high level of co-variability amongst these environmental variables ($P < .001$). Unsurprisingly, air and water temperature variates were positively correlated; temperature variables co-varied inversely with water levels, discharge, barometric pressure, and precipitation.

Multi-day mean Somass River water temperature indices were negatively correlated with upstream water levels (e.g., Sproat water levels ($r = -0.59$), Stamp water levels ($r = -0.54$)) and to a lesser extent, barometric pressure ($r = -0.45$) and a 3-day cumulative total precipitation index ($r = -0.32$) (Figure 18 - Figure 21).

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[18] WSC Station 08HB008, 1913-2010, available at http://www.wsc.ec.gc.ca/applications/H2O/index-eng.cfm.

[19] Note that long-term discharge minimums (1913-2010) for the Stamp Alberni station in July/August were 2.7 and 1.0 cms, respectively.

[20] Note also that average July and August discharge in 2009 were much less: 6.8 and 1.7 m^3/s, respectively.

[21] Sproat River water levels were not available at the time of this analysis, but were added to the plot when made available on the Water Survey of Canada hydrological data website in July 2011 (Figure 16). Sproat Lake water levels, which were used as a proxy for Sproat River water levels, are highly correlated with the latter (Spearman rank $r = 0.98$, $n = 179$); preliminary statistical analyses indicated no significant improvements in parametric and non-parametric regression analyses based on Sproat River levels.

Temperatures in the Stamp River were, in turn, most correlated with Stamp water levels (r = -0.63) and air temperatures (r = 0.57), followed by: barometric pressure (r = -0.48) and precipitation (r = -0.26) (Figure 22).

Sproat River water temperatures were highly correlated with the 10-day backward moving mean air temperature (r = 0.74), followed by: Sproat Lake level (r = -0.53); Sproat River level (r = -0.41); 7-day cumulative total precipitation (r = -0.55); and the 7-day cumulative mean barometric pressure (r = -0.45) (Figure 23 - Figure 24).

3.1.6. Autocorrelation in Environmental Variates

All variables exhibited significant auto-correlations that would bias parametric estimates (e.g., correlation and regression coefficients) away from zero and artificially inflate significance levels of associations between environmental and salmon migration variables due to a lack of independence. However, most environmental variates displayed significant autocorrelations at time spans of less than one week – time lags of 1 to 3 days characterized temperature (air and water), precipitation, and Stamp water level variables, while Sproat Lake water levels and barometric pressure also displayed weak but significant auto-correlations greater than 15 days. Weekly mean values were obtained for all environmental and salmon response variates to reduce the effects of autocorrelations of less than one week. Though this reduced the number of observations from (typically) 62 (days) to 8 (weeks), the significance of the predictive relationships was improved (see results below), due to a reduction in the "noise" in the data.

3.2. PIT TAG RECOVERIES

3.2.1. Tag Recoveries in Fisheries

Landings from commercial fisheries occurring in Alberni Inlet included 23 tag recoveries, including 12 in the gillnet fisheries, and 11 in the seine fisheries (Appendix Table IV). The majority of these tags originated from ocean tagging operations, but three recaptured fish had been tagged at the Papermill Dam site, indicating that at least some fish returned to Alberni Inlet after in-river tagging operations. Time to capture ranged from 2 to 44 days. No information on location of capture was available; thus, it was not possible to determine distance travelled.

Three tagged fish were reported captured in sport or First Nation food fisheries (Appendix Table IV). Two ocean-tagged fish were recovered; one in Numukamis Bay in Alberni Inlet, two days after tagging, and another in the food fishery at the Silver Bridge location in the lower Somass, 14 days after tagging. One fish tagged at the Papermill Dam was landed at the Clutesi Haven Marina, 3.7 km downstream, 4 days after tagging.

3.2.2. Total Somass Sockeye Migrant Tag Recoveries

After removal of erroneous[22] and duplicate tag detections at each antenna site, there were a total of 1,114 tag detections across all sites.[23] A few valid tag recovery records were omitted from migration analyses, including:

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[22] Eleven tag codes occurring in the detection data with no match in the tagging operations data (representing < 1% of the number of unique tags detected) were considered transcription errors and omitted from all analyses (Appendix Table 1).

[23] This is a non-unique tally, since some tags were detected at more than one site, as expected.

- tag records from 5 tagged fish released below Sproat Falls to test the Sproat fishway antennas;
- 2 tags that fell back below the Sproat detection site but re-transited the Sproat antennas several days later (the last date of transit was kept); and
- 24 tags that navigated the Stamp fishway but fell back and were detected passing through the Sproat fishway several days later; these records were excluded from GCL-bound tag analyses, but included for Sproat-bound analyses.

Total unique detections of 891 tags in freshwater from a pool of 2,809 tagged fish represents an overall Somass Sockeye tag recovery rate of 31.7%.

Partitioning these data into marine and river tagging locations, the calculated tag recovery rate ranged from 28.6% for all ocean-tagged fish (426), up to 35.2% for all river-tagged fish (465). This comparison indicated a differential loss rate of 6.5% associated with fish tagged in the ocean potentially associated with fishing mortality or diversion rates of co-migrating Sockeye bound for Henderson Lake. However, the latter accounted for no more than 5% of total returns of Barkley Sound Sockeye in 2010 (D. Dobson, DFO, pers. comm.) suggesting a maximum of 74 unrecovered ocean-tagged fish might be accounted for in the Henderson system. Removing these fish from the calculations yielded a 30.1% recovery rate for ocean-tagged fish.

3.2.3. Recoveries at the Sproat Fishway

A total of 596 tagged fish were detected at the Sproat antenna array, representing 21.2% of the total fish tagged. Of these, 258 were ocean-tagged (17.4-18.3% of the *Argent 1* tag releases, depending on prior omission of 74 possible Henderson fish) and 338 were river-tagged (representing 25.6% of Papermill Dam tag releases).

Of the 596 tag detections, a total of 24 tags (12 ocean-tagged and 12 river-tagged) arrived at the Sproat detector arrays after previously passing through the Stamp array. This indicates that a small proportion of Sproat-bound Sockeye swim some distance beyond the Sproat/Somass confluence, with perhaps as many as 4% of the stock actually reaching Stamp Falls, before falling back and ascending the Sproat River.[24]

These totals are exclusive of five fish tagged below the Sproat Falls fishway for antenna testing on June 1st, of which only four were detected at the fishway. One was detected the same day, two were detected four days later on June 5th, and one was detected on June 6th. The undetected fifth fish might be considered a tag-mortality[25]. Alternatively, it may have bypassed the fishway and antennas after tag application. Bypass estimates at the Sproat fishway in early June were approximately 1.3% (Jeff Till, DFO, unpub. data).

A 2.0% tag detection failure rate at the Sproat fishway was calculated based on 12 tags detected at antenna 1 at the Sproat fishway that were undetected at antenna 2. However, not all fish that entered the fishway were assumed to have passed antenna 2 as some may have backed out to ascend the falls (bypassing the fishway), or expired due to stress (mortality). An alternate estimate, based on 1 missed tag detection at antenna 1 that was detected at antenna 2 suggested a detection efficiency of 99.9%. These methods indicate a tag detection efficiency range of 98.0 – 99.9%.

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[24] Note that no tags were detected at Stamp or GCL antennae that were previously detected at Sproat.

[25] Mean water temperatures at the site were not recorded for early June dates, but were likely well below 17°C, and therefore not implicated as a stressor contributing to fish mortality.

3.2.4. Recoveries at the Stamp and Great Central Fishways

A total of 316 unique PIT tags were detected at the Stamp antenna array, and 227 were detected at the GCL array for a total of 543 fishway detections in the Stamp River system. A total of 225 unique fish tags were detected at both Stamp and GCL antenna arrays. Another 94 fish were detected at the Stamp array but not at GCL, and 2 fish[26] were detected at GCL but not at Stamp. However, 24 Stamp tag detections were later tallied at the Sproat array (and therefore re-assigned to the Sproat stock), leaving 70 fish detected at Stamp only. Based on this information, the number of unique GCL-bound tags can be estimated[27] at 297 fish[28], representing 10.6% of the total fish tagged.

The two tags detected only at the GCL antenna may reflect tag detection failure rate at the Stamp array (which is of low likelihood since there are two antennas in operation), or migrant bypass rate at the Stamp fishway. One was coincident with a prolonged battery change (~1.5 hrs) at the Stamp fishway two days prior to detection at the GCL antenna, while the other likely ascended the falls without using the fishway on or around August 9.

The 70 tag detections at Stamp Falls[29], which were not subsequently detected either at the GCL array as might be expected, or at Sproat Falls, represent an estimated 23.6% of GCL-bound fish. Since these "missing" tags likely do not represent bypass further upstream at the GCL fishway[30], they must be attributed to some combination of:

1. en-route mortality between Stamp Falls and the GCL or Sproat fishways; and/or
2. tag detection failure at the GCL fishway.

Given that 24 Stamp tag detections were later detected at Sproat (7.6% of Stamp tag detections; 4.0% of all Sproat tag detections), it may be that 7.6% or more of the 70 missing tagged fish included in the GCL-bound estimate actually attempted to return to the Sproat system, but were not detected, perhaps due to en-route mortality, bypass at Sproat Falls, or tag detection failure at the Sproat array, while the rest continued upstream to Great Central Lake, but passed undetected through the single-antenna configuration at the GCL fishway[31]. If it is assumed that all fish passing the Stamp array were destined for Great Central (which we now know is not true), then, based on an estimated 297 GCL stock tag detections, the detection failure rate of the GCL antenna was 21.9%.[32] If, on the other hand, all 70 Stamp tag detections not detected at GCL actually diverted to Sproat (but died en-route) were added to the 24 that were detected at Sproat, then the tag detection failure rate at GCL falls to zero.[33] This does not account for en-route mortality, which was not possible to determine from this information.

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[26] These included one ocean-tagged and one river-tagged fish.

[27] The estimated total number of GCL stock Sockeye tags = $94_{STP} + 2_{GCL} + 225_{STP\&GCL} - 24_{SPR} = 297$.

[28] Of these, 169 were ocean-tagged (11.4-12.0% of the Argent I tag releases, depending on prior omission of 74 possible Henderson fish) and 128 were river-tagged (representing 9.7% of Papermill Dam tag releases).

[29] Including 34 ocean-tagged and 36 river-tagged fish.

[30] The observed bypass rate at the GCL fishway was essentially zero all season (Appendix Table 2; Jeff Till, DFO, unpub. data).

[31] Detection efficiency may have been diminished at this site due to known voltage fluctuations in the unit.

[32] Maximum GCL Tag Failure Rate = $(316_{STP} - 24_{STP\text{-}to\text{-}SPR} - 227_{GCL}) / 297_{GCL\text{-}Bound} = 21.9\%$

[33] Minimum GCL Tag Failure Rate = $(316_{STP} - 24_{STP\text{-}to\text{-}SPR} - 70_{STP\text{-}Not\text{-}GCL} - 227_{GCL}) / 297_{GCL\text{-}Bound} = -1.7\%$. The negative balance indicates an over-estimate of the number of "missing" fish diverting to Sproat (70), meaning that at

The estimated total of 297 GCL stock tags, therefore, represents the upper bound of GCL stock tag detections, with the lower bound of 227 GCL stock tags calculated by omitting the 70 unknowns. The upper proportion of uniquely detected tags in the Stamp system would then be 10.6-10.9% of the total number of tagged fish (depending on prior omission of 74 possible Henderson fish). However, if the 70 unknowns are omitted, it is only certain that 8.1-8.3% of all tagged fish actually arrived in Great Central Lake. Partitioned by tagging location, the rate of GCL stock tag recoveries for ocean-tagged fish ranges from 11.4 to 12.0%, and from 6.9% to 9.7% for river-tagged fish.

A 1.7% tag detection failure rate at the Stamp fishway was based on four tags detected at antenna 1 but not at antenna 2, plus one tag that was detected only at antenna 2. Again, not all fish that entered the fishway should be assumed to have passed antenna 1 as some may have fallen back, and subsequently bypassed the fishway or died trying. Based on the sole detection at antenna 2 that was undetected at antenna 1, the detection failure rate was reduced to 0.32%. A review of the missed detection determined that a battery change was conducted 16 minutes prior to detection at antenna 2 and that the array was temporarily off when the fish was likely passing antenna 1. Taking this into account, detection efficiency at the Stamp Falls array was estimated to range from 98.3% to 100% when in operation (i.e. powered).

3.2.5. Stock Composition

Overall stock composition based on tag detections was estimated at 67% Sproat and 33% GCL, substantially different from the official stock escapement ratio of 57% Sproat.[34] (Estimated stock composition during ocean-tagging operations was 61% Sproat and 39% GCL; for river-tagging, 73% Sproat and 27% GCL.) This imbalance in the tag distribution may have implications for which sub-system's environmental factors were most influential on pooled tag analyses.

Peak migration time, as estimated using tag dates for river-tagged fish plus the tag detection dates for ocean-tagged fish lagged back in time[35] to the lower Somass, occurred in the week of July 11-17th. Sproat Sockeye apparently predominated in the months of June, July, and August, with weekly Sproat composition ranging from 69% in June and July, to 58% in August, and 40% in September (Figure 25, Table 5).

The weekly proportion of tagged to untagged sockeye at Sproat and STP arrays indicated that a higher proportion of tagged fish were tallied at the Sproat fishway. The overall proportion of ocean-tagged fish detected at Sproat was, on average, 30% higher than expected, relative to Stamp fishway detections (Figure 26, left). Sockeye tagged in-river (at Papermill Dam) showed an even larger disproportion (42%; $P < 0.001$; Figure 26, right) than those that were tagged in the marine environment. Possible reasons for this unexpected finding are presented in the Discussion.

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least some of the 70 missing tags were actually GCL-bound, but died enroute or went undetected at the GCL antenna. This puts the lower bound on GCL tag detection failure at ~ 0.0%.

[34] Official stock ratio based on adjusted counter-based escapement estimates (all ages) of 456,436 to Sproat Lake and 296,957 to GCL (unpub. data, Diana Dobson (DFO) South Coast Stock Assessment January 2015).

[35] Time lags of 3 days to Stamp and Sproat fishways and 5 days to GCL were based on the modes of river-tagged fish detections (see Section 3.5 below).

3.2.6. Survival

Overall, 919 of 2,809 tags were accounted for at in-river arrays and through fishery monitoring (449 ocean tags and 470 river tags). The remaining 1,890 tags were not recovered at any point following tagging. The most likely causes (in order) are: 1) fishery harvest; 2) natural or tagging induced mortality; 3) tagging of non-Somass stock (i.e., 5% loss to Henderson system); 4) tag loss; or 5) missed detections at arrays. Tag detection failures were estimated to be insignificant (<2%) and tag loss was assumed to be low (1%), therefore neither were considered in the estimate.

The number of tags detected in the Somass watershed from each weekly tagging session was variable for both marine and freshwater operations. Sockeye tagged at Papermill Dam (PMD) showed the widest range in survival from a high of 53.8% for the July 6 group to a low of 15.2% for July 21 (Table 6; Figure 27, top). There was no apparent trend over time with relatively high survival early (July 1: 49.2%), middle (July 13: 48.7%) and late groups (Aug 11: 50.8 %). Low survival releases (July 8, July 21, and August 4) averaged 20.3 ± 5.4% while the high survival releases were significantly different at 50.6 ± 2.2%.

Fish tagged in the marine environment aboard the Argent 1 had a similar overall survival compared to those tagged at PMD (29.3% vs. 33.7%). However, there was far less variability between weekly groups with a range of 17.8% to 36.4% (Figure 27, bottom). There was not a significant difference in survival between early (June) and late (July) releases at 31.9 ± 4.6% vs. 23.4 ± 5.5% but declining survival over time was apparent (r_s= 0.52). This was consistent with increasing harvest rates over the study period (Figure 31).

Landing sites for commercial fisheries were monitored June 28 through August 4 by DFO staff. A total of 68,459 Sockeye from gillnet and seine fisheries were inspected revealing 58 adipose clips pertaining to PIT tagging activities (a small number of Sockeye with healed adipose clips were also present in the population from hatchery releases in Henderson Lake, which were distinguishable from PIT tagged fish). Unique IDs were retrieved from 23 of the 58 clipped fish revealing 20 were from ocean-tagging and 3 from river-tagging operations. The mean recapture time for ocean tagged fish was 14.9 ± 6.0 days although 4 of the 20 fish were caught 37-44 days after tagging. The three fish tagged at PMD were recaptured 8-22 days later. Without more intensive monitoring of recoveries in all fisheries, it is difficult to determine the fate of fish, which were not detected at in-river arrays.

3.3. SOCKEYE MIGRATION STOP/START EVENTS

3.3.1. Fishway Counters and Tag Counts

Total daily tag recoveries (from ocean tagging operations only[36]) and fish counter Sockeye totals, aligned by date and location (lower Somass), indicate reasonably proportional coverage of Sockeye migration timing by the ocean tagging operations (Figure 28). From these data it appears that Sockeye migrants bound for Great Central Lake displayed six active migration periods (AMPs) between 10-June and 15-

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[36] Since only the ocean-tagged fish were sufficiently randomly mixed by the time they arrived at the Somass, relative to the weekly pulsed release of river-tagged fish, the ocean-tagged datasets' detection frequency were more representative of the natural migrant population.

September (Figure 29). The first two AMPs in June were characterized by Stamp/Somass River water temperatures of approximately 15°C or less. Harvest rates during this period were low, ranging from 0-25%, and likely not a significant factor in the June migratory events (Figure 31).

The third AMP, commencing 30-June, peaked at approximately 17,000 fish per day. This migration event may have been precipitated by the only rainfall event between late June and early August. As water temperatures subsequently rose towards 20°C by 10-July, migration fell to 2,000 fish per day. Migration rates then oscillated between 5,000 and 18,000 fish per day, apparently in response to changes in water temperature, rapid changes in Stamp water level, or barometric pressure (as there were no precipitation events). However, weekly harvest rates ranged from 33-39% of the total run during this period, which may have contributed to observed changes in the migration rates.

Another, much smaller, AMP occurred between late July and early August. By the third week of July, however, harvest rates had begun to climb to 50%, and then to 82% by the first week of August, which was likely responsible for the relatively depressed level of migrants during the AMP. Thus, the associated early-August stop event was most certainly confounded by, if not directly related to, harvesting activities, which remained heavy (80-90%) for the rest of August[37]. A final start event for Great Central Lake migrants in early September was characterized by sporadic precipitation, and water temperatures steadily falling below 20°C, in addition to negligible exploitation (<10%); this pulse didn't so much terminate, as diminish gradually, as migrant numbers tailed off naturally over the following weeks.

Sproat migrants displayed a similar pattern, with the addition of an initial batch of migrants moving upstream in early June at average water temperatures of 15°C (Figure 30). A second AMP commencing near 26-June was associated with temperatures of approximately 18°C, and appeared to terminate as Sproat water temperatures surpassed 20°C prior to 10-July. The third AMP after 10-July, however, appears to have commenced while temperatures were elevated, but technical problems associated with the automated counter equipment resulted in lost data between 04-July and 03-August. Though it is clear that Sproat fish were actively migrating in the Sproat River during periods when mean daily water temperatures had consistently surpassed 20°C on or around 20-July, and extending to 04-September, the lack of accurate data obscures the actual migration pattern, and the relation of migratory start/stop events to environmental conditions is largely indiscernible. Evidence of one stop event exists in early July (near the 8th) that may be attributed to mean Somass water temperatures surpassing the 20°C mark. However, the event is also confounded to some degree by concurrent fishery harvest impacts (30-39%; Figure 31).

Due to a consistently high level of fishery exploitation in 2010, it is not possible to determine with any statistical certainty whether the stop, start, and duration of migratory events are strictly a function of changes in environmental conditions.

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[37] Since Somass water temperatures remained elevated above 20°C for most of August, these fish may have not fared particularly well, had they not been harvested.

3.3.2. Estimating Fishway Counts From Tag Counts

In an attempt to use PIT tag recoveries as a predictor for migrant Sockeye stock populations (and missing daily population estimates), stock-specific predictive relationships of Sockeye migrants ("adults" only – Sockeye jacks and non-Sockeye estimates were removed) as a function of tags detected yielded significant relationships ($r_S \sim 0.60$; Figure 32). However, in both cases, predicted values consistently under-estimated known migrant counts (Figure 33), indicating poor model goodness-of-fit, likely due to insufficient tag detections during periods of peak Sockeye population migration. Thus, missing migrant count data could not be effectively estimated from the tag count data.

3.4. TRANSIT TIME THROUGH FISHWAYS

3.4.1. Fishway Comparisons

Parametric and non-parametric ANOVA comparisons indicated significant differences in fish swim speed over the distance between antennas at Stamp versus Sproat arrays, at least for certain portions of the season. Of fish that triggered both antennas in a fishway only once (i.e., successfully ascended the fishway on the first attempt; n = 316), swim speeds were 2-3x faster ($P < 0.001$) in the 18-meter Stamp array (i.e., average speed: 11.5 m/min), relative to fish transiting the 27-meter Sproat antenna array, which averaged 4.6 m/min (Figure 34; Table 7; Table 8). Swim speeds in the Stamp fishway were faster than in the Sproat fishway for all weekly comparisons through the season also, though significance ranged from weak ($P < 0.10$) to strong ($P < 0.01$; Table 9). There were no significant trends or differences in swim speeds between weeks within each fishway, however (Table 10).

These results indicate fishway transit speeds were consistently lower at Sproat, with little evidence of a seasonal effect at either site in 2010. Median duration of fish in the Sproat fishway (between antennas) ranged from about 8-30 minutes, compared to 2-10 minutes for fish in the Stamp fishway (Figure 35).

Fish often required multiple attempts to ascend the fishway, thereby triggering one or both antenna detectors multiple times before clearing the array. A total of 288 fish at Stamp and Sproat fishways were detected at the lower antenna multiple times and the upper antenna only once, representing fish that fell back within the fishway at least once before ultimately exiting successfully past antenna #2. A higher proportion of Sproat-bound tagged fish fell back in this fashion (n = 234, 39% of Sproat tags detected), compared to detections in the Stamp fishway (n = 54, 17% of Stamp tags detected; Table 11). Transit speeds were less for Sproat-bound fish (mean 2.7 m/min versus 10.0 m/min at Stamp; Table 12; Figure 36). These fish also took longer to transit the lower antenna at the Sproat array, taking about 12 minutes from first attempt to last clearance of the first antenna before exiting past antenna #2, compared to ~8 minutes at the lower antenna at the Stamp array ($P_{KW} = 0.0004$, n = 288; Table 13; Figure 37).

A total of 131 fish passed both antennas but fell back below antenna #2 before finally exiting the fishway (i.e., triggering antenna #1 only once, but antenna #2 multiple times) including 71 at Sproat (12% of Sproat tags detected) and 60 at Stamp (19% of Stamp tags detected) (Table 14). Again, these fish were typically faster moving at Stamp (4.5 m/min vs 2.8 m/min; $P_{KW} = 0.04$; Figure 38; Table 15). However, there was no significant difference between sites in the length of time (about 11-13 minutes) between first and last detections at the second antenna (Figure 39; Table 16).

3.4.2. Influence of Migrant Density

High concentrations of fish at the fishways did not appear to have a detrimental effect on fishway passage in 2010, at either the Stamp or Sproat Falls sites, for the available dates of counter observations[38].

At the Sproat fishway, where net hourly up-counts could be matched with date-and-hour-specific fishway transit times[39], the relationship between fishway transit speed (meters per minute) and migrant density was essentially flat ($P > 0.5$, $n = 138$) for hourly migrant counts of zero to 600+ per hour (Figure 40, top). Non-parametric analysis also showed no significant difference in transit speed category versus migrant density levels (Figure 40, bottom).

Migrant density may however be a factor in entering the Sproat fishway: for fish that were detected multiple times at antenna #1 near the fishway entrance, there was a positive relationship with concurrent migrant counts ($r^2 = 0.10$; $P < 0.001$) associated with occasional delays of 15-40 minutes at migrant densities of 400 or more fish per hour (Figure 41). Non-parametric Spearman correlation was weaker ($r^2 = 0.03$, $P = 0.03$).

When summarized at the daily level, Sproat migration density maintained a positive but weak relation with length of time of passage at Sproat fishway antenna #1 ($r_s = 0.30$, $P = 0.06$, $n = 40$ days), in addition to fishway transit speed ($r_s = 0.31$, $P = 0.05$, $n = 40$ days) (Figure 42). GCL mean daily migrant counts – lagged back two days from the counter site – were not significantly correlated with Stamp fishway access, exit, or transit times, which is not surprising, given the two-day lag.

3.4.3. Influence of Environmental Conditions

At the Sproat fishway, where mean hourly water temperatures could be matched with hourly PIT tag data, higher Sproat River water temperatures were significantly associated with slower swim speeds between antennas (Figure 43 (top); $r_S = -0.18$; $P = 0.001$; $n = 321$). A non-parametric frequency analysis based on categorization of transit speeds above and below thermal thresholds of 19-21°C indicated maximum chi-square statistic (differentiating between high, medium, and low swim speeds) at 20°C (Figure 43 (bottom); $P_{\chi 2} = 0.018$).

Stratifying the data by hourly migrant count category indicated possible crowding effects at densities greater than the 90th percentile of 200 fish ($P_{\chi 2} = 0.0004$; $n = 46$), with predominantly low swim speeds evident above 20°C, and high swim speeds restricted to temperatures below 20°C (Table 17). A similar response in swim speed to temperature category was weakly evident at lower migration densities (<200 fish per hour; $P_{\chi 2} = 0.08$; $n = 90$; Table 18).

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[38] Net up-counts for valid counter observations were used as an index of the number of upstream migrants; interpolated hourly estimates when counters were malfunctioning were excluded from the analysis.

[39] Hourly analysis at the GCL fishway was not possible (only one antenna installed), nor at the Stamp fishway, since GCL hourly fishway counts would need to be lagged back to the Stamp site by two days, effectively obscuring any hour-specific relationships.

When summarized at the daily level (Figure 44), Sproat fishway swim speeds were negatively correlated with water temperature (r_p = -0.24; P = 0.05; n = 69) and positively correlated with discharge (r_p = 0.27; P = 0.02; n = 72). A weak positive correlation existed also between delays at antenna #1 and water temperature (r_p = 0.21; P = 0.08; n = 69).

At the Stamp fishway (Figure 45), swim speed between antennas was only weakly correlated with daily mean water temperature (r_p = -0.21; P = 0.11; n = 61) but positively correlated with discharge (r_p = 0.29; P = 0.02; n = 64). While there was a higher frequency of repeat tag detections at Stamp antenna #2 (noted in Section 3.4.1 above), the length of time (minutes) between first and last tag detections at antenna #2 was inversely related to discharge levels (r_p = -0.31; P = 0.01; n = 64).,.

Spearman rank correlation coefficients further indicated (Table 19) that fishway swim speeds (meters per minute) between antennas were the most highly correlated fishway indicators with environmental variables. At the Sproat site (Table 20), fishway *transit speed* (from last detection at antenna 1 to first detection at antenna 2) was negatively correlated with multi-day moving average daily water temperature indicators in the Stamp/Somass system (r_S = -0.16, P < .001, n = 447) and same-day Sproat River water temperatures (r_S = -0.10, P = .03, n = 447), but positively correlated with multi-day Sproat River flows and lake water levels (r_S = -0.10, P = .03, n = 450). These results suggest that higher water temperatures and/or lower water levels negatively affect swimming speed, and/or interfere with Sproat fishway navigability (Figure 44).

The effects of water level were more pronounced than water temperature for fish navigating the Stamp fishway. For the latter, the *navigation speed* (fish swim speed from first detection at A1 to last detection at A2) was weakly and negatively correlated with the 4-day backwards moving average water temperature (r_S = -0.11, P < 0.08, n = 285; Figure 45; Table 19). While fishway *transit speed* (between Stamp antennas) was only weakly associated with daily discharge (r_S = 0.10, P = 0.08, n = 285), overall *navigation rate* (fish swim speed from first detection at A1 to last detection at A2) was significantly associated with higher water levels (r_S = 0.12, P = 0.05, n = 285) and same-day precipitation (r_S = 0.13, P = 0.03, n = 285). Reduced frequency of repeat detection and total time in association with increased daily precipitation (at antenna 1; r_S = -0.13, P = 0.03, n = 288) and increased discharge (at antenna 2; r_S = -0.16, P < 0.01, n = 285) likely contributed to the positive relationship for speeds at higher flow levels.

3.4.4. Predictive Model Estimation

Stepwise predictive model selection based on r^2 improvements retained same-day Stamp River daily discharge and Stamp River 7-day moving average water temperature indicators as significant predictors of overall tag speed (meters/minute, log-transformed) in the Stamp fishway (Table 21). However, the optimum Akaike Information Criterion (AICC) was found for the Stamp River daily discharge indicator only, which was selected for the final predictive regression model based on stepwise LAR methods (Table 22), supporting the notion that higher water levels (up to 1.22 m) were associated with improved fish navigation through the Stamp fishway in 2010.

Stepwise model selection for Sproat fishway transit speed based on r^2 improvements retained a variety of indicators, including Somass and Sproat water temperature and water levels as significant predictors of tag transit speed (meters/minute, log-transformed) between antennas in the Sproat fishway (Table 23). The optimum Akaike Information Criterion (AICC) was, however, indicated for the Somass River 3-day water temperature indicator only, which was retained for the final model (Table 24). The full model suggests that higher lake water levels (up to 60.4 m as measured at the Catalyst intake pipe, or approximately 44 m^3/s flow in the Sproat River) and cooler water temperatures (< 19°C) would facilitate migrant movements in the Sproat fishway. The reduced model suggests that conditions in the Somass River may be the most important factor affecting fish condition and swimming capacity upon arrival at the Sproat fishway.

3.5. MIGRATION TRAVEL TIME

One Sockeye behavioural variate that was easily and consistently provided by the PIT tag dataset is related to migrant travel time between tagging location and tag detection locations. Factoring individual tag travel time (days) into the known distance travelled (km) enabled statistical comparisons of fish travel rate (km/d) between stocks, detection sites, and tagging dates and locations.

3.5.1. River-tagged Fish Travel Time

The distribution of all tag detections for fish tagged at Papermill Dam indicate that Sockeye took roughly the same number of days to swim 5.8 km to Sproat Falls as they did to Stamp Falls (10.2 km). The modal and median values for both these locations were 3.0 days (Figure 46)[40]. Though the mean travel time was larger for both stocks (4.4 ± 6.6 days to Stamp Falls; 4.6 ± 5.3 days to Sproat Falls) than the most frequent travel times, the distribution for all tag detections at both locations was skewed to the right due to a small number of fish that took 50 days or more to pass through the Stamp and Sproat detection antennas. When these outliers were omitted from the analysis by restricting the data to the lower 90th percentile of travel time (equivalent to a maximum of 12 days), the medians and modes remain the same (3.0 days), but the robust mean travel times were decreased by a day to 3.4 ± 1.6 days (Stamp Falls) and 3.6 ± 1.6 days (Sproat Falls) (Figure 47; Table 25). For the Stamp fishway, 95% of migrants entered in 6 days and the Sproat fishway in 7 days.

For the 91 fish detected at the GCL antenna, the largest number (mode) of fish made the journey from Papermill Dam in 4 days, and 50% of the detections occurred within 5 days (Figure 46), with a mean of 5.4 ± 1.9 days (Table 25). No outliers were removed from the GCL data, since the maximum days calculated for any fish passing through the GCL fishway was 12 days. As the maximum travel time to GCL was considerably less than it was for the four "outliers"[41] omitted from the Stamp data, this might suggest that Sockeye that take approximately two weeks or more to reach the Stamp fishway do not successfully attain the GCL fishway, perhaps due to mortality from depleted energy reserves. However, due to potentially high tag detection failure rates at the GCL site, it is not possible to attribute this difference to en-route mortality with any certainty.

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[40] Calculation of travel time based on the precise time of tag detection did not substantially change the location statistics (mean, median, etc.) or reduce the variance for either in-river or ocean-based taggings.

[41] These fish were tagged on July 13th, 21st, or August 4th, when Stamp-Somass water temperatures were below 19-20°C and unlikely to be directly related to lengthy travel times recorded.

Comparing mean fish travel rate (km/d) factors out the different freshwater distances involved, isolating stock effects or environmental conditions. Apparent swim speeds differed significantly between stocks ($P < 0.05$). Average travel speed for river-tagged Sockeye from Papermill Dam to the Sproat fishway was less than 2 km per day, compared to mean travel rates of 3.5 km/d to the Stamp fishway, and about 5 km/d to GCL (Table 25; Figure 47, bottom). The contrast in swim speeds to Sproat and Stamp fishways suggests holding delays or diversions may be affecting Sproat fish to a larger degree.

For Stamp-to-GCL distances alone, fish travelling speed averaged close to 9 km/day, 2-3 times the rate of travel to the Stamp site[42].

Partitioning the tag travel data by date of tagging demonstrated no strong time trends in average travel speed for either stock to any of the tag detection locations ($P > 0.15$), though maximum variability in travel rates appears in mid-to-late July for Stamp passage, and mid-August for Sproat migrants (Figure 48).

3.5.2. Ocean-Tagged Fish Travel Time

Ocean tagged fish naturally exhibited more variability in travel time to upstream detection locations due to the greater distances involved[43]. The frequency distribution of travel time for both stocks share a similar bi-modal pattern, with prominent peak travel times of 9 days (Sproat) and 10-11 days (Stamp), followed by another peak at 16 days (Sproat) and 17 days (Stamp) (Figure 49). Modal peaks may be associated with weekly fishery closures.

The corresponding modal peaks at the GCL counter occurred at 11-13 days and 18-19 days (not shown). The median (50%) of all ocean tags detected at GCL took 16.5 days to arrive, with a mean of 17.3 ± 7.1 days. Again, the maximum travel time recorded at GCL (41 days) was less than the maximum travel time recorded at Stamp Falls (85 days). At least 20 fish were detected at Stamp whose travel time exceeded the slowest fish arriving upstream at Great Central, suggesting that Sockeye reaching Stamp Falls much more than a month after arriving at the Somass are unlikely to arrive at the spawning grounds in Great Central Lake, most likely due to one or more chronic conditions (e.g. depleted energy reserves, infection from pathogens etc.). Again, it is not possible to partition these differences between en-route mortality and GCL tag detection failures with any degree of certainty.

Sproat Sockeye generally outpaced GCL-bound Sockeye in 2010, with the lower 90% percentile (omitting outliers taking 36 days or more) averaging 13.1 ± 7.0 days (median 10 days) compared to the lower 90% percentile of Stamp Falls arrivals averaging 15.7 ± 7.5 days (median 14.5 days) (Figure 50, Table 26). When translated into average travel speed to account for the different distances involved, data comparisons demonstrated only a weak significant difference between stocks (Sproat: 4.6 km/d; Stamp: 4.0 km/d; Kruskal-Wallis chi-square test: $P = 0.08$). When compared to the river-tagged data, these results indicate that only the Sproat stock exhibited a slow-down in the freshwater environment ($KW\chi^2$ test: $P < 0.001$).

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[42] And a maximum of 20 km/d.

[43] However, there were no systematic trends or significant effects on travel time for either stock due to geographical differences in ocean tagging location.

In contrast to river-tagged fish which displayed no significant time trends in travel speed, ocean-tagged fish show a weakly positive trend ($P = 0.07$), indicating that travel time in Alberni Inlet tends to increase as the season progresses (Figure 51).

3.6. TAG TRAVEL TIME AS A FUNCTION OF ENVIRONMENTAL CONDITIONS

3.6.1. Correlation Analysis

3.6.1.1. Ocean-Tagged Fish

Of the lower Somass water temperature variates examined, GCL-bound fish travel rates were most correlated with multi-day moving average water temperatures in the Somass and Stamp waterbodies 3-7 days before detection at the Stamp fishway ($r_s \sim -0.52$, $P < 0.0001$, $n = 144$), indicating the fish travelled approximately twice as fast at 16°C than 20°C (Figure 52 - Figure 57). GCL fish also travelled faster at higher Stamp River water levels ($r_s \sim 0.35$, $P < 0.0001$, $n = 144$), and after rainfall during the previous 2-3 days ($r_s \sim 0.35$, $P < 0.0001$, $n = 144$) (Figure 54, Figure 56).

Similar correlations are found for Sproat-bound fish. Travel rates to Sproat, however, were equally correlated with a multi-day mean Sproat water level index ($r_s \sim 0.53$, $P < 0.0001$, $n = 241$) (Figure 55), as they were with Somass or Sproat water temperatures ($r_s = -0.54$, $P < 0.001$, $n = 241$) (Figure 52, Figure 53). Precipitation appeared to play a strong role for Sproat fish as well ($r_s \sim 0.41$, $P < 0.0001$, $n = 241$) (Figure 56).

When the tag data and environmental variates are reduced to weekly means and medians to minimize the statistical bias associated with short-term auto-correlation effects (Figure 58 - Figure 63), correlations were actually improved for Stamp travel rates as a function of Somass water temperatures ($r < -0.95$, $P < 0.001$, $n = 9$) and Stamp water levels ($r > 0.90$, $P < 0.001$, $n = 9$), but eliminated for precipitation and barometric pressure indices ($P > 0.05$). For Sproat fish, Sproat water level indicators emerged as the most significant correlates ($r \sim 0.96$, $P < 0.001$, $n = 8$), with Somass water temperatures ($r \sim 0.94$) and Sproat water temperatures ($r \sim 0.92$) close behind. The 3-day cumulative total precipitation index remained weakly significant ($P = 0.06$), while the barometric pressure index was eliminated ($P > 0.40$).

3.6.1.2. River-Tagged Fish

Statistical relations between fish travel rates and environmental conditions were weaker for river-tagged fish (Figure 64 - Figure 69). While Somass water temperatures remained an important factor for GCL fish, correlations were reduced ($r_s \sim 0.3$, $P < 0.0004$, $n > 122$), indicating that fish were less sensitive to water temperature conditions once they had arrived at the tag and release site at Papermill Dam. GCL-bound fish showed no relation to Stamp River water levels or precipitation though barometric pressure appeared to be significant ($r = -0.25$, $P < .005$).

Sproat fish travel rates were negatively correlated with Somass temperatures 3-4 days prior ($r_s \sim -0.33$, $P < 0.0004$, $n = 322$), and remained correlated with Sproat water level indices ($r_s = 0.30$, $P < 0.0001$, $n= 322$) and the 7-day logarithmic precipitation index $r_s \sim 0.2$, $P < 0.005$).

For data summarized at the weekly level, statistical relations were also somewhat weakened (Figure 70 - Figure 75), relative to ocean-tag analyses. Somass temperatures remained relevant ($r \sim -0.7$, $P < 0.05$, $n = 8$), as did precipitation indices (r

~ 0.7, $P < 0.05$), but other variates were dropped as significant correlates. The only variates summarized at the weekly level that remained significant for Sproat fish were multi-day moving total precipitation indices ($r \sim 0.9$, $P < 0.05$, $n = 8$).

3.6.2. Multi-variate Regression Analysis

While these correlational results tend to implicate high water temperatures, low precipitation, and low water flows throughout the system with lower fish migration rates, it has already been shown that all these variates co-vary linearly with air and water temperature to the point where the exact driver(s) of migration behaviour remain unclear. To distinguish the relative influence or importance of the various correlated factors on Sockeye travel time, the coefficient of variation (CV) for variates retained in stock-specific multi-variate stepwise LAR regression models was used to define the level of explained variance attributed to any retained environmental effects.

For river-tagged fish, the LAR model retained only Somass daily maximum water temperature as a significant predictor of individual tag travel rate (km/d) to the Stamp fishway; however, this variate contributed less than 4% to the explained variance, as indicated by its adjusted partial r^2 value (Table 27). For Sproat-bound fish, the 7-day moving average barometric pressure index contributed 10% of the overall 14% of explained variance, followed by Somass daily mean water temperatures lagged 3 days (3%), and the date (2%; Table 28).

For ocean-tagged fish, the LAR model identified the 7-day moving average Somass mean water temperature indicator and the date as significant predictors of individual tag travel rate (km/d) to the Stamp fishway; these variates accounted for 19% of the explained variance (Table 29). For Sproat-bound fish, the LAR model retained the 3-day moving average Somass mean water temperature indicator and the 3-day moving average Sproat River mean water temperature indicator as significant predictors, which accounted for 18% of explained variance (Table 30).

When data summarized at the weekly level were used in the LAR multi-variate models, the travel rate of ocean-tagged fish bound for GCL was still "explained" by the same variables, but to a much stronger degree (date: 57%; 7-day moving average Somass mean water temperature indicator: 34%). Both parameter estimates are negative, indicating that slow travel rates are associated with high water temperatures, late in the season. If date is removed from the model (since seasonal water temperature trends exist), the negative effect of Somass water temperature accounts for up to 74% of variation in Sockeye migration rate. Stamp River water levels are also included as a positive effect in the final model (CV = 17%; Table 31).

As for Sproat-bound fish, the weekly mean 3-day moving average Somass mean water temperature indicator explained 96% of fish travel rate variation (Table 32).

These results indicate that Somass River water temperature was the principal environmental driver in Sockeye travel rates in 2010 for both Great Central and Sproat Lake stocks, contributing 74 – 96% of the explained variability in migration rate. Stamp River water levels appear to have played a lesser role for GCL-bound Sockeye, while neither Sproat River water temperatures nor Sproat water levels seem to have had any effect on Sproat-bound fish.

3.6.3. Categorical Analysis of Means

Categorical data classifications for Sockeye tag migration rates and environmental variates are listed in Table 33. Sockeye migration rates were categorized into roughly equal relative speed quantiles: slow (<2 km/d), medium (2-4 km/d), and fast (>4 km/d). Water temperature observations were classified as: cool (<=18°C); warm (18-20°C); hot (20-22°C); and very hot (>22°C); water level and barometric pressure data were categorized into data quartiles; and precipitation was partitioned into High (> 1 mm/d), Low (0.001 – 1 mm/d) and Zero (no precipitation) bins.

Analysis of mean (ANOM) ocean-tagged fish migration rates indicated that travel rates for both GCL and Sproat fish were significantly below average at temperatures of 19°C or more in the lower Somass (Figure 76). The slowest migration rates were associated with water temperatures above 20°C, though too few tagged fish (n = 3) migrated in this temperature category to prove significant. Peak migration rates for both stocks occurred at Somass temperatures less than 17°C. Similar travel rate trends were observed for ocean-tagged GCL fish in relation to Stamp water temperatures, and Sproat fish in relation to Sproat water temperatures (Figure 77), though the latter were always about 2°C warmer than the Somass. Trends related to water temperature were less evident for river-tagged fish, indicating less of a temperature effect at this stage of their migration (Figure 78, Figure 79).

Net migration rates for ocean- or river-tagged GCL-bound fish showed no trends with respect to Stamp River water level categories, though migration rates were depressed at mid-range water levels, significantly for in-river tagged fish (Figure 80). Ocean-tagged Sproat-bound fish also showed no trend with Stamp water levels, but were sensitive to Sproat water levels, showing improved travel rates with higher Sproat water levels (Figure 81). River-tagged Sproat fish showed little systematic response to either Stamp or Sproat water levels, though, again, migration rates were depressed at mid-range water levels (Figure 82).

Analysis of mean travel rates, categorized according to barometric pressure levels for the 7-day mean index, indicated no significant differences for either stock or tag set, suggesting that this environmental variate has little effect on migration rate (Figure 83, Figure 84).

Sockeye travel rates were associated with precipitation levels (7-day cumulative total index), at least for ocean-tagged fish (Figure 85), for which low rates coincided with periods of no precipitation, while highest rates were coincident with rainfall accumulations of 1 mm or more per day. For river-tagged fish, cumulative precipitation appeared to have little or no systematic effects on migration rate (Figure 86).

3.6.4. Multiple Correspondence Analysis

To compare the relative influence of the environmental variables on migration rate, all factors were incorporated into a multiple correspondence analysis (MCA). MCA plots by stock demonstrated a relatively strong association between travel rates (km/d) and various environmental variables for fish ascending the Sproat system, and weak or no effects for GCL-bound fish[44], for the levels of measurements attained in 2010. Slow travel rates for Sproat fish were most associated with warm Somass (>18°C) and Sproat

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[44] Potentially due to the disproportionately low number of tags placed on GCL-bound fish.

(20-22°C) temperatures, low Sproat water levels, and periods of no precipitation, while fast travel rates were associated with cooler water temperatures and some precipitation (Figure 87). These "cool/wet" and "warm/dry" categorical factor combinations defined the majority of the range of the first dimension of the MCA, contributing approximately 55% of the principal inertia statistic (Table 34). The categories contributing the most to the range in this spectrum were: 1. cool Somass temperatures <18°C; 2. relatively cool Sproat temperatures 18-20°C; 3. low Sproat water levels; and 4. high precipitation levels (>1 mm/d). The second dimension, largely defined by low barometric pressure and very warm Sproat River temperatures (>22°C) categories, represented another 16% of the overall inertia, but these categories were not closely associated with Sproat fish travel rates.

Top travel rates for ocean-tagged GCL-bound fish were associated with cool Somass temperatures and high precipitation levels (though less strongly than for Sproat fish – the principal dimension of the analysis defined less than 34% of the correspondence (Table 35)) – but not with Stamp River temperatures or water levels (Figure 88). In fact, extremes in GCL travel rates were more closely associated with Sproat water temperatures than Stamp conditions (Figure 89), illustrative, perhaps, of the thermal influence of the Sproat tributary on Somass mainstem conditions. However, the additional inertia attributed to the first dimension was only 1%, indicating no real improvement in the weak overall association of GCL travel rates and environmental conditions.

For river-tagged fish, the correspondence of travel rate and environmental conditions is even less clear. While, for Sproat fish, the environmental variables align along the first dimension in a similar fashion as for ocean-tag data, with "cool/wet" conditions and "warm/dry" conditions at opposite ends of the spectrum, these categorical clusters were only loosely associated with fish travel rates – contributing only 35% to the overall inertia statistic (Table 36). The low fish speed category (0-3 km/d) was located near the plot centroid zone of low association (x=0, y=0), indicating no apparent influences in either dimension, and thus no association with the warm/dry collection of environmental variables (Figure 90). Medium fish speeds (3-6 km/d) were associated with the cooler, wetter end of the spectrum, but distanced from the cluster by effects in the second dimension, which was largely defined by differences in barometric pressure. High fish speed data (>6 km/d) were not represented in the river-tagged dataset.

GCL-bound river-tagged fish travel rates were all located near the plot centroid, again indicating little or no influence from environmental conditions at that stage of their migration (Figure 91). Although the primary axis of the correspondence analysis accounted for 37% of overall inertia (Table 37), this dimension was not clearly defined by any environmental categories.

The MCA categorical analysis flags a couple of items of interest. First, migration rates appear to be more sensitive to environmental conditions for Sproat fish than for GCL fish, at least for the range of conditions and numbers of fish in stock-specific tag-groups observed in 2010. The primary influence, which is common to both stocks, appears to be Somass water temperature. The analysis does not rule out a positive effect due to relatively high levels of precipitation for either stock, however, barometric pressure appears not to be a driving factor. Although Sproat water temperature and level are additional influential factors affecting Sproat migration, upper extremes in Sproat water temperatures do not appear to exert any additional impact on travel rates beyond the apparent negative influence of river temperatures in the range of 20-22°C.

3.6.5. Frequency Analysis

Stock-specific two-way frequency analysis of the response variate (travel rate bin) against individual environmental factors indicated, for ocean-tagged fish, highly significant differences ($P < 0.05$, Mantel-Haenszel χ^2) in the numbers of tags moving at each travel rate for different levels of most environmental factors. For example, the vast majority (96%) of GCL-bound tags travelling faster than 4 km/d were associated with Somass water temperatures of 19°C or less, while the majority (65%) of the tags travelling only 0-2 km/d encountered Somass temperatures greater than 19°C (Table 38). The highest levels of association with both GCL and Sproat fish travel rates, as indicated by Somers' D statistic Z-scores[45], were observed for Sproat, Somass and Stamp water temperatures ($P = 0.0001$) and Sproat water levels ($P = 0.0001$) (Table 38 - Table 51). Stamp water levels ($P = 0.0004$), and barometric pressure ($P = 0.006$) also figured prominently for GCL fish, but the precipitation index was not significantly associated with GCL travel rates ($P = 0.17$). The barometric pressure index was only weakly associated with ocean-tagged Sproat-bound fish travel rates ($P = 0.06$). Stamp water levels were not associated with Sproat travel rates.

By contrast, river-tagged fish travel rate groups were much less strongly associated with environmental factors. GCL-bound fish were not associated with any environmental variable categories at the $\alpha = .05$ level, though weakly discordant with both Stamp water levels ($P = 0.08$) and Sproat water temperatures ($P = 0.06$) (Table 52, Table 53). Sproat-bound river tags appeared to be most highly associated with Stamp water levels ($P = 0.0001$), though again, discordantly (Table 54). This would suggest that, as river flows increased, fish travel rates decreased, as if higher flows were impeding migration, which is unlikely at the water levels observed. Other, lesser associations for Sproat fish included: precipitation ($P = 0.01$), Sproat temperature ($P = 0.02$), and Stamp temperature ($P = 0.05$) (Table 55 - Table 57). Note the limited number of tags (2) in the "high speed" category of river-tagged Sproat fish – this likely limits the statistical power of the associative tests, as well as the interpretability of the results.

Returning to the ocean-tagged dataset, to test whether environmental variables highly associated with the response variable, such as Sproat water temperature and Sproat water level, may be confounding or interacting with each other, three-way frequency analyses were performed for travel rate versus the water temperature indicators, holding the category of the secondary environmental variate (water level, precipitation, barometric pressure) constant. The resultant Cochran-Mantel-Haenszel (CMH) statistics all indicate that strong linear associations remain for at least one stratum between ocean-tagged GCL fish migration rates versus Somass water temperatures while controlling for Stamp water level, barometric pressure and precipitation levels (Table 58 - Table 60); as well as Sproat water temperatures, controlling for Sproat water level, barometric pressure, and precipitation levels (Table 61 - Table 63).

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[45] Positive Somers' D statistic Z-scores indicate concordance between rows and columns (i.e., increasing values in rows with increasing values in columns); negative Z-scores indicate discordance (i.e., increasing values in one dimension with decreasing values in the other).

4. DISCUSSION

4.1. ENVIRONMENTAL CONDITIONS

Although the year 2010 was classified as a “warm” PDO and ENSO year in the North Pacific, typically characterized by warm, dry summer weather, local temperature conditions in the Somass watershed were closer to the long-term norms (1971-2000). Air temperatures during peak Sockeye migration timing (July-August) in 2010 averaged 19-20°C (well within long-term averages), after a cooler-than-average spring characterized by a significant drop in temperatures in late May and early June relative to previous years. Consequently, daily mean water temperatures remained slightly lower than normal in the early summer months in the Somass River (mean 19.2°C, max 22.4°C), and in the Stamp River (mean 18.8°C, max 22.2°C), despite a dry spell of minimal precipitation in July and lower than average precipitation in August. Not until the latter half of August did water temperatures in the Stamp/Somass system exceed 20°C for any length of time. However, water temperatures in the Sproat River surpassed 20°C in early July, and remained there until the end of August, averaging 21.6 ± 1.4°C (range 18.2 – 23.9°C). The lack of precipitation in July and August resulted in reduced discharge in the Sproat system, which fell to about half the long-term average by August. This may have resulted in warmer water temperatures in the Sproat system than are typical for a summer of average air temperatures, with implications for Sproat Sockeye migration and reproductive condition.

Correlation analyses demonstrate that strong associations exist between the various environmental factors, even when filtered for first-order auto-correlative time trends. This indicates a high level of inter-dependence amongst the variables that poses a challenge for discerning the most influential environmental drivers of fish migration behaviour, such as stop migration events, and migration travel rates.

4.2. PIT TAG RECOVERIES

Of a total 1,487 PIT tags applied in Alberni Inlet and 1,322 Sockeye tagged in-river at Papermill Dam pool, 891 were detected by PIT antennas, for a 32% recovery rate. Ocean tags comprised 29% of the total, compared to 35% for river tags, suggesting a 6% differential in recovery rates attributable to inlet fishing and natural mortality and/or diversion rates for tagged Sockeye belonging to the co-migrating Henderson Lake stock. Of the ocean-tagged fish, it may be assumed that approximately 5% (~74 tagged fish) were bound for the Henderson system. However, no tags were recovered from the Henderson fence or Clemens Creek stream walks or swims[46].

Given that fish tagged in-river were not directly exposed to commercial or sport fisheries, the 35% recovery rate of in-river tagged fish appeared low. Overall, the low tag recovery rates bear further consideration and research, especially for in-river tagging operations, at least to partition the lost tags between natural and fishing mortality for management considerations.

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[46] Tag detection rates would be low to non-existent in Clemens since stream assessments were done via swims at higher water levels and PIT tagged fish carried no obvious external tag. Further, Clemens carcasses are not sampled annually, and were not in 2010, so the opportunity for recovery was minimal.

Though not quantifiable in this study, it is likely that tag mortality was more prevalent for fish tagged in-river, due to the additional thermal and osmoregulatory stress on the fish during tagging operations (Goniea et al. 2006).

Fewer than 1% of tag recoveries were from sport, commercial, or First Nation fisheries. This may imply that natural mortality might account for the majority of the 6% differential, however, since PIT-tagged fish were not externally tagged for ready identification, it is unlikely that area fishers would have been a reliable recovery source if they were aware of the program, and therefore it is unknown what proportion of harvested fish were tagged and what proportion of tag recoveries were unreported. Should a PIT tagging study be repeated, more focus should be placed on observer and fisher awareness.

About 67% of tag recoveries occurred at the Sproat fishway, and 33% at the Stamp fishway, which does not reflect DFO's 'official' stock composition of Somass Sockeye returns in 2010 (~57% Sproat).

Approximately 7.6% of fish detected at Stamp were later detected at Sproat, but no Stamp detections were previously detected at Sproat. This represents a minimum diversion rate – if all fish detected at Stamp but not at GCL had in fact attempted to return to Sproat, the diversion rate might be up to 30%. Though the fact that Sproat fish occasionally divert up the Stamp does not inherently affect Great Central/Sproat stock proportion estimates (since the GCL spawners are tallied at the lake outlet), it does indicate an additional energy expenditure for a proportion of Sproat migrants that has not hitherto been estimated.

Maximum detection failure rates at the Sproat and Stamp fishway locations were estimated at 2.2% and 1.7%, respectively. Assuming double that failure rate for the single-antenna GCL array (i.e., 4-5%) puts an upper bound of approximately 25% on the proportion of fish that fall-back to the Sproat system after transiting the Stamp array. It was impossible to partition the Stamp/GCL tag detection discrepancy into GCL detection failure versus en-route mortality between the sites. Hence, provision of known estimates of detection efficiency at the GCL fishway would be a key step in determining to what extent en-route mortality is a significant factor in the upper Stamp River, if at all.

In principle, there should be some utility in PIT tag operations and recovery as a means of independently estimating upstream migrants in the event of automated counter failures, as occurred frequently in 2010. However, after taking into account the fact that PIT tags were only applied to adult fish, and that some proportion (~5%) of ocean-tagged fish migrated into the Henderson system, the predictive estimates for adult spawners often underestimated counter-derived estimates by 50% or more. In the Sproat case, this may be due to insufficient range of paired observations, since counter failures were prevalent during peak migration periods throughout July, thereby curtailing the predictive regression relationship at the upper end. At Great Central Lake, counter problems were less prevalent, thus paired observations were available at the full range of migrant densities, but the relationship between GCL counts and Stamp fishway tag detections may be obscured by the multi-day temporal gap in fish travel time between fishway sites. This might be rectified by enhancing the tag detection array at GCL. The clustered release of in-river tags and the generally low tag recovery rate (32%) may be contributing factors to the poor fit of the stock-specific tag-to-spawners predictive relations.

The weekly proportion of tagged to untagged sockeye at Sproat and GCL arrays indicated a disproportionate number of tagged fish were tallied at the Sproat fishway. The proportion of both ocean-tagged and river-tagged fish detected at Sproat was, on average, 30-42% higher than expected, relative to Stamp detections (Figure 26). Sockeye have a strong fidelity to the lake in which they reared as juveniles (Quinn et al. 1987), so this result was an unexpected finding. Possible explanations include bypass or inaccuracies at one or both counters, non-random tag applications, behavioral response by sockeye to stress from tagging, or selective en-route mortality between Papermill and Stamp Fishway locations.

While the Stamp counter was functional and calibrated frequently throughout the season, the Sproat counter was intermittent from July 12-19 (50 hours of valid counts total), and non-functional from July 19-31, for which daily counts were estimated based on linear interpolation methods, introducing significant uncertainty into Sproat escapement estimates, and therefore obscuring the seasonal and overall stock composition ratio (pers. comm., Jeff Till, DFO). If Sproat counter data significantly underestimated actual Sproat migrants, it is possible that the ratio of Sproat-bound to GCL-bound fish was higher and the actual stock composition ratio closer to the tag-based ratio. However, assuming the GCL escapement was accurate at 348,651 sockeye, the number of Sproat-bound migrants would need to be >700,000 fish (instead of 457,017) to match the overall stock composition derived from tagging operations. That level of escapement does not match with field observations. Furthermore, adjustments to the daily and total Sproat escapement estimates to account for counter failure would likely result in fewer than 457,017 escaped Sproat sockeye, yielding a stock ratio closer to 50:50, and further diverging from the tag-based stock composition estimates.

Ocean-based tag application during test-fishing operations likely involved a higher proportion of Sproat fish tagged, at least early in the season (June), when Sproat sockeye typically comprise a higher proportion of the returns. In fact, the 61% Sproat proportion for ocean-based tags does not appear to be explained sufficiently by the timing of tag operations, since ocean tagging occurred weekly from mid-June until the middle of August. Likewise, the timing of weekly applications of tags in-river through July and August, presumably on randomly mixed stock migrants, does not reasonably explain the consistently high disproportion (~73%) of detected Sproat-bound tags for river-tagged fish,.

Other possibilities involve factors above the Papermill site, including tag detection failures and/or bypass at the Stamp fishway site. Either possibility would have resulted in significant tag detections occurring at the GCL site only, which was not supported by the data (<1% of tags were detected only at GCL).

Assuming no harvest mortality upstream of Papermill selectively removing GCL-bound sockeye[47], two possibilities remain, involving either altered behavioral response posttagging resulting in a disproportionate number of tagged sockeye (especially river-tagged) migrating to the Sproat system, or increased en-route mortality for GCL-bound sockeye. While it has been shown that heat stress and discharge impacts can induce migratory behaviour changes (Goniea et al. 2006; Roscoe et al. 2011), it is also known that fish tagged in-river incur more stress than ocean-tagged fish due to the physiological impacts of: (a) warmer water conditions; (b) conversion from marine to freshwater osmoregulation; and (c) gear type (Martins et al. 2011).[48]

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[47] Some unauthorized harvesting has been observed in recent years in Danny's Pool (Sproat River), but no reports of fishing effort in the upper Somass or lower Stamp rivers have been documented (pers. comm., Diana Dobson. DFO).

Therefore, it may be possible that, due to the cumulative stress of tagging activities, sockeye bound for the more distant Great Central Lake altered their migration route away from their natal lake and diverted to the nearest[49] body of cold water[50]. Arguably, the most hydrologically-arduous and energy-depleting point of migration for GCL-bound sockeye is the ascension of Stamp Falls (including finding and transiting the fishway), which might provide a trigger-point for a decision to fall-back to the Sproat River, despite higher water temperatures in the Sproat system. This could explain the 94 tagged fish which were detected at Stamp Falls, but did not reach the GCL array. Twenty-four of these fish were later detected at the Sproat fishway[51], while 70 were never detected again[52] and likely succumbed to stress. While significant (though unquantified) mortality at Sproat Falls was observed in 2010, crews were not routinely present on the lower Stamp where significant mortalities may have existed unobserved (pers. comm., Jeff Till, DFO). Therefore it is possible that, under warm mid-summer water conditions in 2010, a minimum of 8% and possibly up to 30% of tagged fish tallied at Stamp Falls fell back (or expired), reducing the proportion of surviving GCL-bound tagged fish. Nor does this account for fish that fell-back below Stamp Falls without being tallied at the Stamp fishway. Though highly speculative at this time, this concept calls for further investigation in relation to the objectives set out in this study.

4.2.1. Migration Timing

Apparent migration timing for ocean tags coincided with stock migrant run timing estimates, however, migration stop/start/duration events that may have been associated with or precipitated by changes in environmental conditions were confounded by coincident harvest rates of 50-90% of weekly run size. Thus, statistical analysis of migratory events in relation to environmental conditions was not possible in 2010. Attempts to model daily stock migrant populations from tag detections ($r \sim 0.70$) consistently under-estimated known migrant counts, indicating poor model goodness-of-fit, likely due to insufficient tag detections during periods of peak Sockeye population migration.

The distribution of all tag detections for fish tagged at Papermill Dam indicate that Sockeye took roughly the same number of days to swim 5.8 km to Sproat Falls as they did to get to Stamp Falls (10.2 km). The modal and median values for both these locations were 3.0 days. Mean travel times were 3.6 ± 1.6 days to Sproat Falls (i.e., 2 km/d), 3.4 ± 1.6 days to Stamp Falls (3.5 km/d) and 5.4 ± 1.9 days to GCL (5 km/d). Ninety five percent of migrants reached the Stamp fishway in 6 days, GCL in 12 days, and the Sproat fishway in 7 days.

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[48] No fish tagged at PMD took more than 12 days to reach GCL which also suggests longer in-river residence times were associated with decreased migration success.

[49] Based on migration data from this study, the shortest route into the cold hypolimnetic water from the mouth of the Somass is via Sproat River (3.6 days compared to 5.4 days to GCL).

[50] The fact that no fish were first detected at the Sproat fishway before detection at the Stamp array also suggests that there is little evidence of random straying between the two systems – it appears to be unidirectional.

[51] Interestingly, half the tags originated from ocean-tagging and half from river-tagging, suggesting the location of tagging was not a driving factor in the diversion rate (Section 3.2.4).

[52] Likewise, about half were ocean-tagged and half were river-tagged (Section 3.2.4).

Accurate estimates of swim speeds for Sproat-bound Sockeye may be confounded by the evidence that some Sproat fish ascend the Stamp River at least as far as Stamp Falls, resulting in actual swim distances longer than the direct route. Full stream antennas in each of the Sproat and Stamp rivers, above their confluence, would be key to quantifying this temporary diversion rate.

Ocean tagged fish exhibited more variability in travel time to upstream detection locations due to the greater distances involved, with prominent peak travel times of 9 days (Sproat) and 10-11 days (Stamp), followed by another peak at 16 days (Sproat) and 17 days (Stamp). Sproat Sockeye generally outpaced GCL-bound Sockeye in 2010, with the lower 90th percentile averaging 13.1 ± 7.0 days (median 10 days) compared to Stamp Falls arrivals averaging 15.7 ± 7.5 days (median 14.5 days). When translated into average travel speed to account for the different distances involved, data comparisons demonstrated only a weakly significant difference between stocks (Sproat: 4.6 km/d; Stamp: 4.0 km/d; $P = 0.08$).

Since swim speed in Alberni Inlet was marginally faster for Sproat Sockeye, the slow-down exhibited by these fish in the freshwater environment attests to the possibility that Sproat fish experienced disproportionately higher delays (holding patterns) or diversions (as noted above) between Papermill and the Sproat Falls fishway. Alternatively, the apparent swim speed may be indicative of bottlenecks at or below the Sproat fishway, likely incurring negative thermal impacts. The apparent difference in swim speeds for GCL-bound Sockeye below and above Stamp Falls suggests that GCL fish also exhibit more holding patterns in the lower river and/or at Stamp Falls where fishway bottlenecks likely occur.

Differences in tag detections between the Stamp and GCL fishways suggest that Sockeye that take approximately two weeks or more between the lower Somass and the Stamp fishway do not successfully pass the GCL fishway. Thus, extremely slow migration rates may be indicative of a loss of fitness and subsequent mortality due to a variety of causes that could include: depleted energy reserves, increased probability of interception in lower river fisheries, losses to predation and/or pathogens. However, confirmation that the majority of the tag detection differences between the Stamp and GCL fishways represent en-route mortality requires more certain estimates of the actual efficiency of the tag-detection array at the Great Central fishway.

4.2.2. Fishway Passage

Sockeye took 2-3 times as long, on average, to transit the Sproat fishway antenna array than the Stamp fishway array in 2010. Automated fish counters at the exit to the Sproat fishway – absent in the Stamp fishway – may have slowed Sproat migrants as they negotiated the plexi-glass tunnels, and thereby influenced the results[53].

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[53] Counters were also installed at the GCL fishway but only one antenna was used in this detection array, so GCL

Most of the time difference involved swimming the distance between antennas, but fish were also disproportionately slower at navigating past the lower antenna at Sproat than Stamp. The higher frequency of multiple detections at Sproat antenna #1 may indicate that lengthier passage times in the Sproat fishway may be at least partly related to accessing the fishway and navigating the lower end. This could be due to the fact that the lower antenna at the 43-meter Sproat fishway is located only 10 meters from the fishway entrance, whereas the lower antenna at the 90-meter Stamp fishway is about 62 meters above the entrance. It is possible that the fish take some time to navigate the first few meters before recognising the flow pattern, becoming trained, and picking up speed as they navigate more cells.

While migrant density did not appear to be a prominent factor affecting swim speeds at either fishway (but see below regarding interactions with water temperature), it was positively correlated with delays at Sproat antenna #1. Maximum delays (exceeding 20 minutes) at antenna #1 appeared at densities of 400+ fish per hour. However, repeated failures of the automated fish counter at Sproat in 2010, coincident with apparently high hourly fish passage rates (Figure 30), likely obscured the relationship. Since only low-to-moderate migrant densities (< 12,000 fish per day) were recorded, this analysis could not rule out density-dependent fishway passage rates occurring when tens of thousands of daily migrants must navigate through PULSAR counter bays.

Fishway transit speeds for a given date-time were inversely correlated with hourly mean water temperature at the Sproat fishway, and displayed significant decreases above a threshold of 19-20°C. Temperature effects on migrant speed were more apparent at migration levels of 200 or more fish per hour. The relations between daily mean temperature and daily discharge versus transit speed at Sproat were similar but weaker. These results suggest that higher water temperatures and/or lower water levels negatively affect swimming speed, and/or interfere with Sproat fishway navigability. The analysis suggested that higher lake water levels (up to 60.4 m as measured at the Catalyst intake pipe, equivalent to approximately 44 m^3/s flow in the Sproat River) and cooler water temperatures (< 19°C) would facilitate migrant passage through the Sproat fishway.

At the Stamp fishway, where environmental indicators summarized only at the daily level were available, water temperature effects on fishway transit speed were less evident, while water level indicators (and precipitation) were positively correlated.

Predictive regression models - based on robust stepwise methods – for fishway swim speed indicators as a function of a variety of independent environmental co-variates selected only the three-day backwards moving average Somass water temperature variable as an important predictor for Sproat fishway transit time. At the Stamp fishway, where average water temperatures never exceeded 22ºC, Stamp daily discharge was selected as the only significant predictor of fishway transit time, indicating that higher water levels (up to 1.22 m) were associated with improved fish passage through the Stamp fishway. The inferences are that high Stamp River discharge rates improve GCL-bound fish passage, whereas, for Sproat-bound fish, high water temperatures in the

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passage time estimates were not feasible.

lower Somass (highly correlated with conditions in Sproat River) negatively influence fish passage at the Sproat fishway, perhaps through accrued energetic stress impacts.

While the influence on fish passage of site-specific structural differences between the two fishways cannot be ruled out (e.g., the taller, more spacious, fishway cells in the Stamp fishway may contribute to faster transit speeds at higher migrant densities), these results may simply also be a function of cooler (1-2°C) average water temperatures and higher (3-4x) discharge rates at the Stamp site relative to the Sproat site. Data deficiencies, including the gaps associated with extended counter failures during peak migration periods, likely confound the analytical results as well.

4.2.3. Migration Rate

Travel speed for river-tagged Sockeye from Papermill Dam to the Sproat fishway was, on average, less than 2 km per day, compared to mean travel rates of 3.5 km/d to the Stamp fishway, and about 5 km/d to GCL. For Stamp-to-GCL distances alone, fish travelling speed averaged close to 9 km/d (max. 20 km/d), 2-3x the freshwater travel rate to the Stamp site. Though this does not rule out possible stock effects on travel rate, the wide range in travel rates for GC-bound fish below, versus above, the Stamp fishway, indicates that apparent differences in travel speeds are likely environmental, as opposed to biological, in origin. Environmental factors may be hydrological (e.g., different pooling opportunities), thermal (different thermal refugia availability), or mechanical (finding the fishway entrance, negotiating the counter bays, etc.). When compared to the ocean-tagged data, these results indicate the Sproat stock (only) exhibited a slow-down in the freshwater environment. Due to a lack of detection antennas at strategic decision-points (i.e., at the mouth of the Somass River, and at the mouth of the Sproat River at its confluence with the Stamp River), it is not possible to ascertain based on these PIT-tag data alone whether significant differences in stock migration rates are due to migration delays (i.e., holding in the estuary and/or in freshwater refugia), or direct biophysical impacts of environmental conditions on swimming speed. Water temperature differentials at the mouth of the Somass and the Stamp/Sproat confluence, and congestion below fishways may be contributing to migration delays. Another factor warranting further research due to the potential impact on stock-specific escapement estimation is the level of diversion (and the associated energetic costs) for Sproat sockeye ascending the Stamp River beyond Stamp Falls before returning to Sproat River.

Though river-tagged fish displayed no significant time trends in travel speed, ocean-tagged fish show a weakly positive trend, indicating that swim velocity in Alberni Inlet tends to increase as the season progresses. In any case, Somass Sockeye travel rates appear to be much lower than for Sockeye in other, longer river systems studied elsewhere.[54]

Parametric regression analyses indicated most significant correlations between weekly means of multi-day mean environmental indicators and stock migration rates. GCL-bound ocean-tagged fish travel rates were most correlated with multi-day moving average water temperatures in the Somass and Stamp waterbodies 3-7 days before detection at the Stamp fishway[55], indicating the fish travelled approximately twice as fast when water temperatures in the Somass and at the surface in Alberni Inlet were 16°C as opposed to 20°C. GCL fish also travelled faster when Stamp River water levels were higher[56], but travel rates were uncorrelated with precipitation and barometric pressure indices. For Sproat fish, Sproat water level indicators emerged as the most significant correlate[57], with Somass water temperatures and Sproat water temperatures close behind. The 3-day cumulative total precipitation index was weakly significant[58], while the barometric pressure index was not correlated with Sproat migration rates. Similar, but much weaker statistical relations were determined for river-tagged fish, indicating that Somass Sockeye are less sensitive to environmental conditions once they have reached the tag and release site at Papermill Dam, 6.5 km from the Somass river mouth. This suggests that, once in upstream migration mode, fish travel rates are no longer a function of average environmental conditions, although there is evidence that stock-specific hydrological[59] conditions may be limiting Sproat Sockeye in-river, migration rates. Observations of differences in the degree of correlation between migration rates and environmental variables for ocean tagged versus river tagged fish also suggest that the "upstream migration go/no-go decision point" occurs seaward of Papermill Dam.

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[54] *c.f.*, 17-39 km/d for Fraser Sockeye (English et al. 2005); 35 km/d for Columbia Sockeye (Fryer et al. 2010; 2011).

To distinguish the relative influence or importance of the various correlated factors on Sockeye travel time, the coefficient of variation (CV) for variates retained in stock-specific multi-variate stepwise regression models[60] was used to define the level of explained variance attributed to retained environmental effect. These parametric analyses indicated that Somass River water temperature was the principle environmental driver in Sockeye travel rates in 2010 for both Great Central and Sproat Lake stocks, contributing 74 – 96% of the explained variability in migration rate. Stamp River water levels appear to have played a lesser role for GCL-bound Sockeye, while neither Sproat River water temperatures nor Sproat water levels seemed to significantly influence Sproat-bound fish. Except for the fact that Sproat Sockeye take twice as long to travel the same distance as GC-bound fish, it appears that Sproat Sockeye migration rates do not co-vary strongly with Sproat River conditions (at the range of environmental condition levels observed in 2010). This may suggest that, unless unknown thermal refugia are available en route, Sproat Sockeye may be exposed to thermal conditions for the duration of the Sproat River migration phase, which could compromise their reproductive fitness. Some research emphasis should therefore be placed on assessment of the biological condition of Sproat Sockeye before and after ascending the Sproat River to understand both the immediate and subsequent biological impacts of this exposure (e.g. on egg or sperm development, reproductive success etc.).

Categorical frequency analyses was applied to the migration rate and environmental data as a complementary non-parametric approach to ranking the influence of environmental factors on Sockeye migration rates, while circumventing the statistical bias inherent in parametric analysis of time-series datasets. As in the parametric tests, river-based tags showed weak or spurious associations with environmental conditions. For ocean-based tags, the highest levels of association for both GCL and Sproat fish travel rates were observed for Sproat, Somass, and Stamp water temperatures, as well as Sproat water levels. Stamp water levels and barometric pressure also figured prominently for GCL fish, while the precipitation index was not significantly associated with GCL travel rates. In addition to the highly significant water temperature effects, the barometric pressure index was weakly associated with ocean-tagged Sproat-bound fish travel rates. Stamp water levels were clearly not associated with Sproat travel rates.

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[55] $r_s \sim -0.9$, $P < 0.001$, n = 9 weeks

[56] $r_s \sim +0.9$, $P < 0.001$, n = 9 weeks

[57] $r_s \sim +0.9$, $P < 0.001$, n = 8 weeks

[58] $r_s \sim +0.6$, $P = 0.06$, n = 8 weeks

[59] In this case, hydrological conditions include both the seasonal volume of discharge in streams and water quality, including the physical, chemical and biological characteristics of water in each sub-basin of the Somass.

[60] Based on Least-Angular-Regression methods which are robust to non-independence in the predictor set.

Three-way frequency analysis statistics were generated for stock migration rates as a function of the categorical water temperature variates, stratified by water levels, barometric pressure and precipitation categories, to control for potentially confounding effects due to the interacting nature of the variates. The resultant Cochran-Mantel-Haenszel statistics all indicate that strong linear associations remain between ocean-tagged GCL fish migration rates versus Somass water temperatures while controlling for Stamp water level, barometric pressure, and precipitation levels; and for Sproat-bound fish migration rates versus Sproat water temperatures, controlling for Sproat water level, barometric pressure, and precipitation levels. While these results do not specifically indicate causation, they are supportive of the correlative and predictive results obtained via parametric analyses that point to water temperatures in the lower Somass as the principle factor in Sockeye migration behaviours, with secondary and likely interaction effects related to water levels, especially for Sproat-bound fish. As noted above, however, environmental conditions in the Somass watershed were relatively moderate in 2010, and the results of this study may not apply to years of more extreme conditions.

5. RECOMMENDATIONS

Some recommendations that arise out of the 2010 Somass Sockeye PIT tag study include: improvements in the experimental design of future PIT tag studies; and maintenance, or addition, of data monitoring activities to facilitate study of Sockeye migration behaviour in the Alberni Inlet and Somass system.

5.1. EXPERIMENTAL DESIGN

1. Conduct a field study to assess short-term and delayed (72-hour) mortality to segregate tag-induced mortalities from natural causes.
2. Randomize river tag releases in future PIT tag studies to obtain statistically testable information on the environmental impacts of freshwater migration timing and travel rates and reduce likelihood of disproportionate tag applications between stocks.
3. Due to a potential effect on migration time associated with ocean tagging location, it is important to accurately specify exact time and location of tag releases to control for differences in distance travelled up the inlet.
4. Target PIT tag studies for Sockeye return years that are forecast to be characterized by extreme environmental conditions and low adult returns, to

maximize the influence of environmental effects, and to avoid the confounding effects of high harvest rates on migration timing.

5. Supplement PIT tag observations with continuously recording archival time and temperature tags that can provide insight into fish behaviour and duration of exposure to specific conditions of temperature and oxygen in Alberni Inlet and freshwater environments (e.g., Fryer et al. 2011).
6. Investigate impacts of fishway access and navigability for a range of water temperatures, water levels and migrant densities, especially for the Sproat fishway, in future field studies.
7. Initiate field research to assess the biological condition and reproductive fitness of Somass Sockeye before and after ascending natal streams to quantify the potential impacts of exposure to reduced water quality and quantity on reproductive capacity and pre-spawn mortality (as in Roscoe et al. 2011).
8. Investigate the influence of lighting on decreasing total travel times and congestion at fishways. All three fishways are potential candidates for night time lighting experiments.

5.2. TAG DETECTION

1. Double-tag fish with a highly visible external tag to ensure fishers and observers are not missing PIT-tagged fish recoveries in fisheries. When used in conjunction with new video-counters at SPR and STP, tag rejection rates could also be determined (i.e. external tag present and no PIT detection). Alternatively, PIT tags could also be attached to visible external tags to limit the possibility of internal infection or damage.
2. Install a double antenna array (during low-water period) at the GCL fishway to enable:
    - Calculation of tag detection efficiency at the GCL fishway, which would help identify:
        - en-route GCL-bound Sockeye mortality rates;
        - diversion rate of Stamp enumerations to the Sproat system; and
        - fish travel time differences above versus below Stamp Falls.
3. Install a full-stream double antenna 'pass-over' array at key locations in the Somass watershed:
    - In the lower Somass, as near as possible to the river mouth, to determine when, and under what conditions, migrants enter the Somass River.
    - In the lower Stamp, above the confluence with Sproat River to assist in:
        - understanding migratory behaviour related to the temperature differential between Stamp/Somass and Sproat flows;
        - determining en-route mortality below the Stamp fishway; and

        - confirming fall-back rates of Sproat sockeye diverting up the Stamp system.
    - In Sproat River above, but as close to the confluence with the Stamp to determine when, and under what conditions, migrants enter the Sproat River.
    - At the weir in Sproat Lake to estimate:
        - actual time of entry into the cold water refuge;
        - mortality associated with ascending Sproat Falls under different environmental conditions; and
        - Sproat fishway bypass rate (non-fishway migrants) to potentially assist with counter calibration.
    - In Taylor River at the head of Sproat Lake or at selected spawning beaches to identify which fish were successful at reaching spawning grounds and link migration behavior/conditions to reproductive success.
    - At the Henderson River counting fence to determine the number of Henderson-bound fish that are tagged. This will provide greater insight into recovery rates at Somass and reveal the temporal and spatial distribution of Henderson-bound Sockeye in Alberni Inlet.
4. Tags represent the least expensive component of the study, therefore it is recommended that a minimum of 5,000 tags (23-mm tags are sufficient) be used in future studies (perhaps applied to the entire test fishery catch) in order to account for lower detection efficiencies of full-stream 'pass-over' arrays.

5.3. ENVIRONMENTAL DATA MONITORING

1. Maintain water temperature data loggers in Somass, Stamp, and Sproat rivers.
2. Maintain the water level logger in Stamp River, and incorporate a new water level data logger in Sproat River, calibrated against discharge data from the Sproat WSC hydrometric station, to circumvent delays in availability of Sproat discharge data.
    - Re-assess covariation in fishway transit variables as a function of hourly estimates of fishway water temperature, water level (or real-time discharge data, and migration density un-confounded by fish counter failures.

ACKNOWLEDGEMENTS

The authors of this paper would like to thank the following entities: BC's LIVING RIVERS TRUST FUND, PACIFIC SALMON COMMISSION, DEPARTMENT OF FISHERIES AND OCEANS and NATURAL RESOURCES CANADA for providing the majority of the funding, and the BC CONSERVATION FOUNDATION for administering the funds; BCCF and DFO staff for their hard work setting up the RFID equipment and capturing and tagging nearly 3,000 fish; the Hupacasath and Tseshaht First Nations for their assistance and cooperation with in-river fish capture; captain and crew of the *Argent 1* for their assistance with ocean capture and tagging; CATALYST PAPER LTD. and BC PARKS for their cooperation with land access; OREGON RFID for their ongoing technical assistance with the RFID equipment and Don McCubbing from INSTREAM FISHERIES RESEARCH for rental of RFID equipment and expertise; DFO personnel who provided data and comments (Diana Dobson, Jeff Till, Peter Hall) and other project team members, all of who played an important role in the successful implementation of this project.

REFERENCES

Birtwell, I.K., and Korstrom, J.S. 2002. A commentary on aquatic degradation in Alberni Inlet, British Columbia, and consequences to juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and adult Sockeye salmon (*Oncorhynchus nerka*). *In*: Cumulative Environmental Effects Management: tools and approaches. Edited by A.J. Kennedy. A symposium held by the Alberta Society of Professional Biologists, Calgary, Alberta, November, 2000. Alberta Society of Professional Biologists, Edmonton, AB. Pp. 441-453.

Boggs, C.T., Keefer, M.L., Peery, C.A., Bjornn, T.C., and Stuehrenberg, L.C. 2004. Fall-back, re-ascension and adjusted fishway escapement estimates for adult Chinook Salmon and Steelhead at Columbia and Snake River Dams. Trans. Am. Fish. Soc. 13: 932-949.

Burt, D. 1999. Production capability of salmonid habitat in selected reaches of the Stamp-Somass river system. Prepared for Ministry of Environment, Lands and Parks by D. Burt and Associates. 102 p.

Connor, B., and Yearsley, B. 2003. Influence of flow and temperature on survival of wild yearling fall Chinook salmon in the Snake River. Trans. Am. Fish. Soc. 23:362-375.

Dare, M.R. 2003. Mortality and long-term retention of passive integrated transponder tags by spring Chinook salmon. N. Am. J. Fish. Manag. 23:1015–1019.

Efron, B., Hastie, T., Johnstone, I., and Tibshirani, R. 2004. Least angle regression. Ann. Statist. 32:407–499.

English, K.K., Koski, W.R., Sliwinski, C., Blakley, A., Cass, A., and Woodey, J.C. 2004. Migration timing and river survival of late-run Fraser River Sockeye salmon estimated using radio-telemetry techniques. Trans. Am. Fish. Soc. 134:1342-1365.

Flom, P.L., and Cassell, D.L. 2007. Stopping stepwise: Why stepwise and similar selection methods are bad, and what you should use. National Development and Research Institutes, NESUG 2007 Proceedings. Accessed online at: http://www.nesug.org/Proceedings/nesug07/sa/sa07.pdf.

Fryer, J.K., Wright, H., Folks, S., Bussanich, R., Hyatt, K., and Stockwell, M. 2014. Limiting factors of the abundance of Okanagan and Wenatchee Sockeye salmon in 2012. Columbia River Inter-Tribal Fish Commission Technical Report 14-01. Portland, Oregon. Available at: http://www.critfc.org/fish-and-watersheds/fishery-science/scientific-reports/

Fryer, J.K., Wright, H., Folks, S., Hyatt, K., and Stockwell, M. 2012. Limiting factors of the abundance of Okanagan and Wenatchee Sockeye salmon in 2011. Columbia River Inter-Tribal Fish Commission Technical Report 12-08. Portland, Oregon. Available at: http://www.critfc.org/fish-and-watersheds/fishery-science/scientific-reports/

Fryer, J.K., Wright, H., Folks, S., and Hyatt, K. 2011. Limiting factors of the abundance of Okanagan and Wenatchee Sockeye salmon in 2010. Columbia River Inter-Tribal Fish Commission Technical Report 11-04. Portland, Oregon. Available at: http://www.critfc.org/fish-and-watersheds/fishery-science/scientific-reports/

Gislason, G.S. 2007. Economic contributions of the Oceans sector to the west coast of Vancouver Island. Report prepared for the Canada Department of Justice. G.S. Gislason and Associates Ltd., P.O. Box 10321, Pacific Centre, 880-609 Granville Street, Vancouver, B.C. V7Y 1G5.

Goniea, T.M., Keefer, L., Bjornn, T.C., Peery, C.A., Bennett, D.H., and Stuehrenberg, L.C. 2006. Behavioral thermoregulation and slowed migration by adult fall Chinook salmon in response to high Columbia River water temperatures. Trans. Am. Fish. Soc. 135: 408-419.

Hyatt, K.D., and Steer, G.J. 1987. Barkley Sound Sockeye salmon (*Oncorhynchus* nerka): Evidence for over a century of successful stock development, fisheries management, research, and enhancement effort. In: H.D. Smith, L. Margolis, and C.C. Wood [ed.] Sockeye salmon (*Oncorhynchus* nerka) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96:435-457.

Hyatt, K.D., McQueen, D.J., Rankin, D.P., and Demers, E. 2011. Density-dependent growth in juvenile sockeye salmon (*Oncorhynchus nerka*). The Open Fish Science Journal 4:1-13.

Hyatt, K.D., McQueen, D.J., Shortreed, K.S., and Rankin, D.P. 2004. Sockeye salmon (*Oncorhynchus nerka*) nursery lake fertilization: Review and summary of results. Environ. Rev. 12:133-162.

Hyatt, K.D., Stiff, H.W., Stockwell, M.M., Luedke, W., Rankin, D.P., Dobson, D., and Till, J. 2015. A synthesis of adult Sockeye salmon migration and environmental observations for the Somass watershed, 1974-2012. Can. Tech. Rep. Fish. Aquat. Sci. 3115: vii + 199 p.

Keefer, M.L., Peery, C.A., Jepson, M.A., and Stuehrenberg, L.C. 2004. Stock-specific migration timing of adult spring–summer Chinook salmon in the Columbia River Basin. Trans. Am. Fish. Soc. 24:1145-1162.

LeBrasseur, R.J., McAllister, C.D., and Parsons, T.R. 1979. Addition of nutrients to a lake leads to a greatly increased catch of salmon. Environ. Conserv. 6:187-190.

Manzer, J.I., Morley, R.B., and Girodat, D.J. 1985. Terminal travel rates for Alberni Inlet Sockeye salmon (*Oncorhynchus nerka*). Can. Tech. Rep. Fish. Aquat. Sci. 1367: 19 p.

Morris, S., and Leaney, A.J. 1980. The Somass River Estuary, status of environmental knowledge to 1980. Special Estuary Series 9: 374 p. Environment Canada, B.C.

Martins, E.G., Hinch, S.C., Patterson, D.A., Hague, M.J., Cooke, S.J., Miller, K.M., English, K.K., and Farrell, A.P. 2011. Effects of river temperature and climate warming on stock-specific survival of adult migrating Fraser River Sockeye salmon (*Oncorhynchus nerka*). Global Change Biology 17(1):99-114.

Quinn, T.P., Wood, C.C., Margolis, L., Riddell, B.E., and Hyatt, K.D. 1987. Homing in wild sockeye salmon (*Oncorhynchus nerka*) populations as inferred from differences in parasite prevalence and allozyme allele frequencies. Can. J. Fish. Aquat. Sci. 44:1963-1971.

Roscoe, D.W., Hinch, S.G., Cooke, S.J., and Patterson, D.A. 2011. Fishway passage and post-passage mortality of up-river migrating Sockeye salmon in the Seton River, British Columbia. River Res. Applic. 27:693–705.

Smith, S.G., Muir, W.D., Williams, J.G., and Skalski, J.R. 2002. Factors associated with travel time and survival of migrant yearling Chinook salmon and Steelhead in the Lower Snake River. Trans. Am. Fish. Soc. 22:385-405.

Statistical Analysis Software (SAS). 2009. SAS/Stat Guide for Personal Computers. Version 9.2 Edition. SAS Institute Inc., Box 8000, Cary NC USA 27512.

Steer, G.J., and Hyatt, K.D. 1987. Use of a run timing model to provide in-season estimates of sockeye salmon (*Oncorhynchus nerka*) returns to Barkley Sound. Can Tech Rep Fish Aquat Sci. 1557: 39 p.

Stucchi, D., Kolodey, A., Birtwell, I., Waldichuk, M., Hyatt, K., and Knapp, W. 1990. Review of the water quality issue in Port Alberni Harbour. Unpublished report to file dated Oct. 18, 1990. Department of Fisheries and Oceans Canada, Institute of Ocean Science, Sidney, B.C. and the Pacific Biological Station, Nanaimo, B.C. 20 p.

Troffe, P.M., McCubbing, D., and Melville, C. 2010. 2009 Cheakamus River Chum salmon escapement monitoring and mainstem spawning groundwater survey. Prepared for BC Hydro - Cheakamus River Water Use Plan. 51 p.

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FIGURES

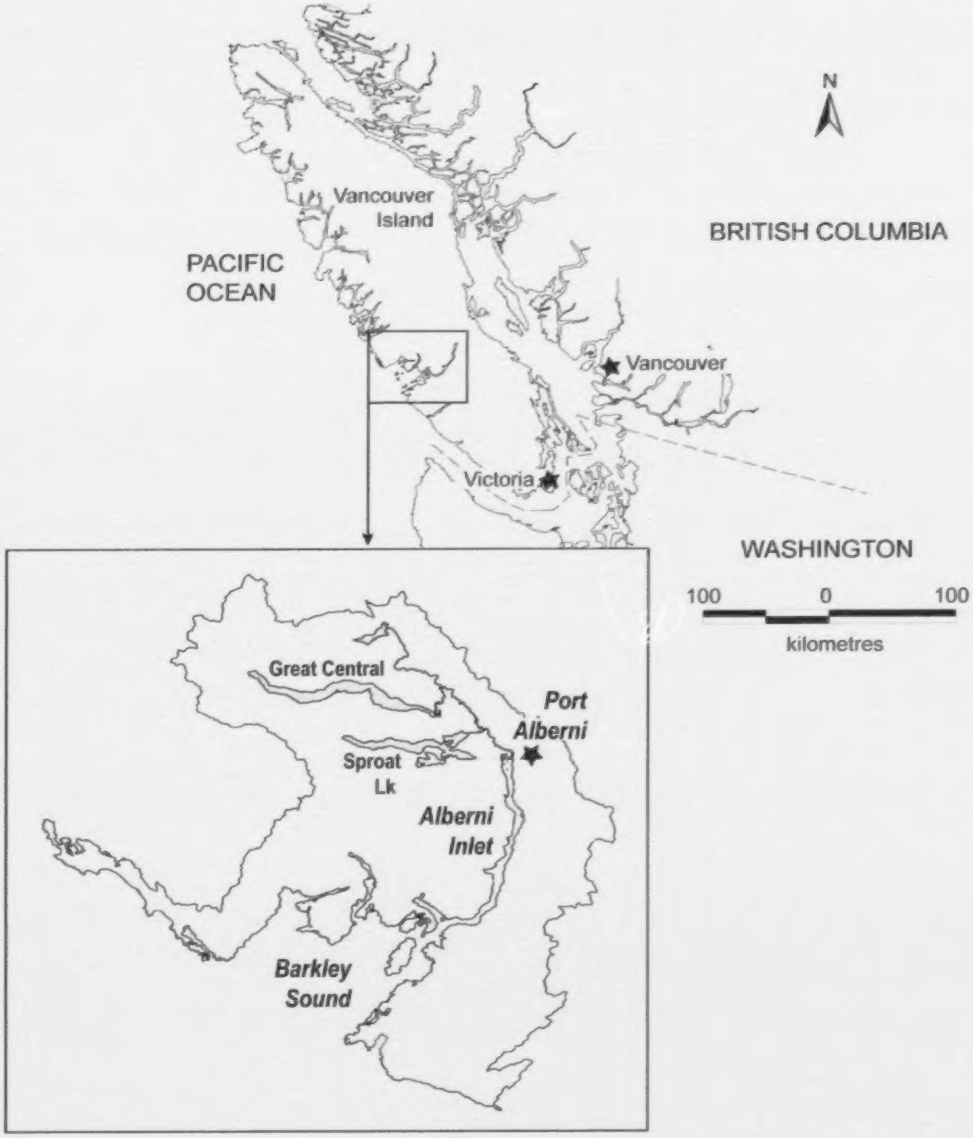
N
Vancouver Island
BRITISH COLUMBIA
PACIFIC OCEAN
Vancouver
Victoria
WASHINGTON
100
0
100
kilometres
Great Central
Port Alberni
Sproat Lk
Alberni Inlet
Barkley Sound

Figure 1. Location of the Somass watershed on the west coast of Vancouver Island, B.C., including principle lakes (Great Central and Sproat) draining into Alberni Inlet, and Barkley Sound.

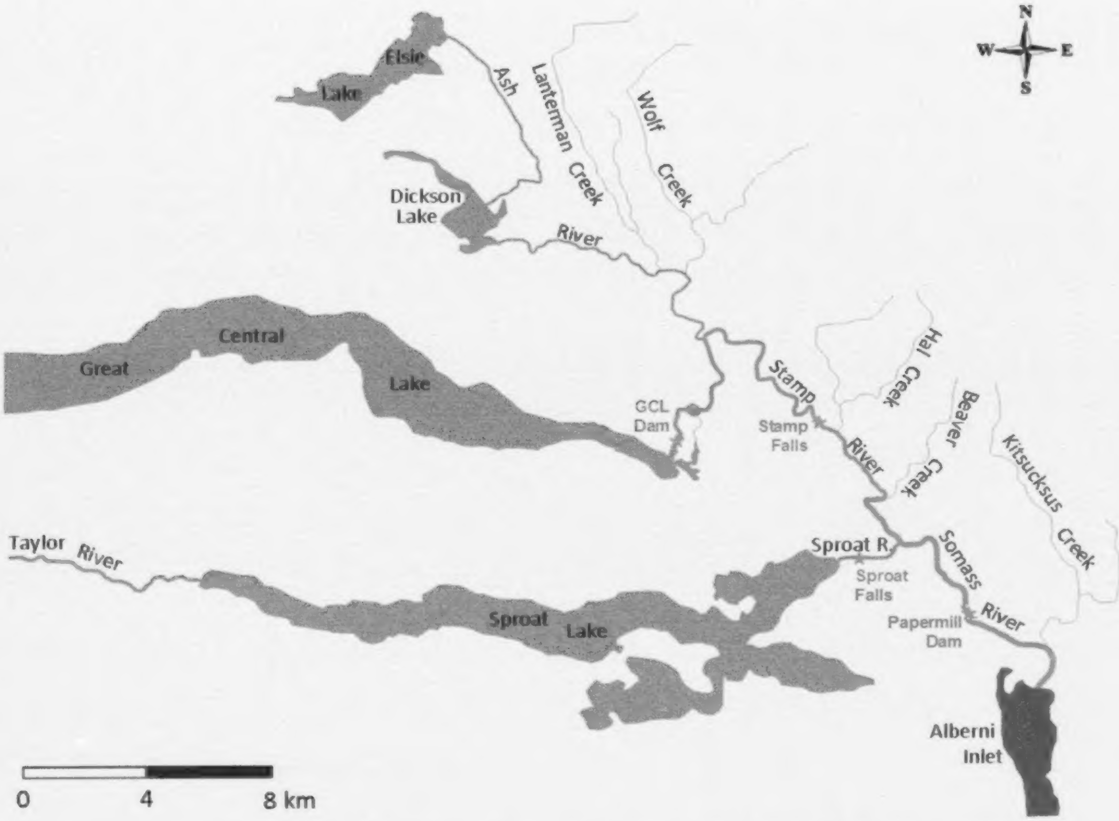
N
W
E
S
Elsie Lake
Ash River
Lanterman Creek
Wolf Creek
Dickson Lake
Great Central Lake
GCL Dam
Stamp River
Stamp Falls
Hal Creek
Beaver Creek
Kitsucksus Creek
Taylor River
Sproat Lake
Sproat R.
Sproat Falls
Somass River
Papermill Dam
Alberni Inlet
0
4
8 km

Figure 2. Map of the Somass River watershed including main tributaries and the location of PIT tag detection arrays.

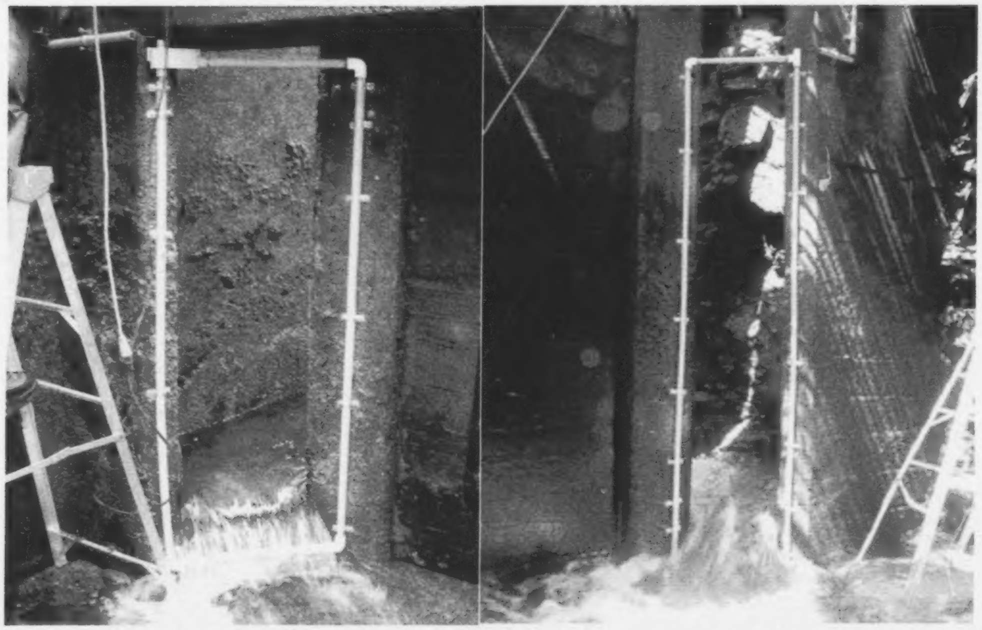

Figure 3. PIT antenna array installed at the Sproat River fishway (left) and Stamp River fishway (right), May 20 - June 4, 2010.

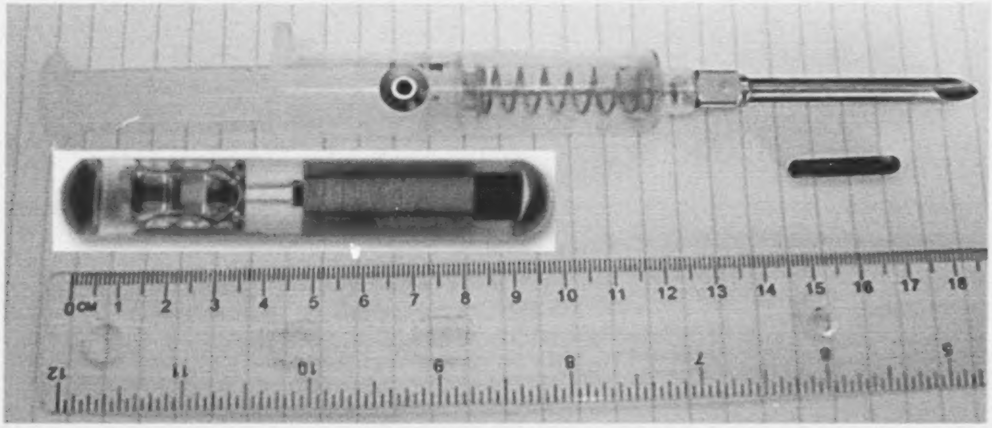
0 CM 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
12 11 10 9 8 7 6 5

Figure 4. HDX 23 mm PIT tag (middle, image courtesy of Oregon RFID), 6 gauge needle and syringe with specialized plunger for tag insertion compared to actual tag size.

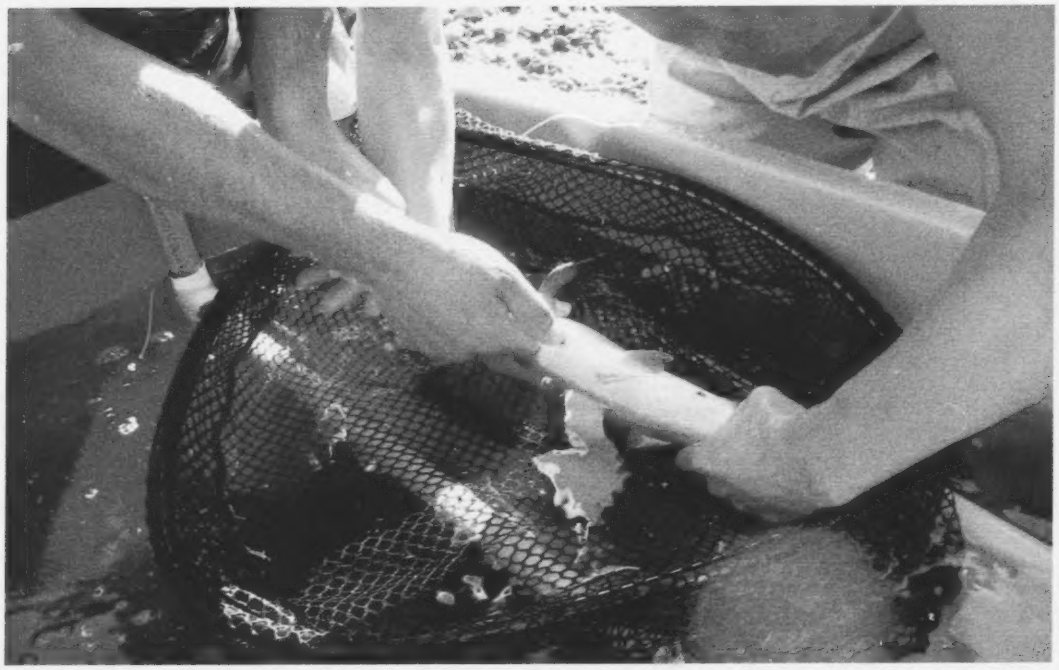

Figure 5. Inserting a PIT tag into an adult Sockeye at Papermill Dam using a fish tote and cradle, July 6, 2010.

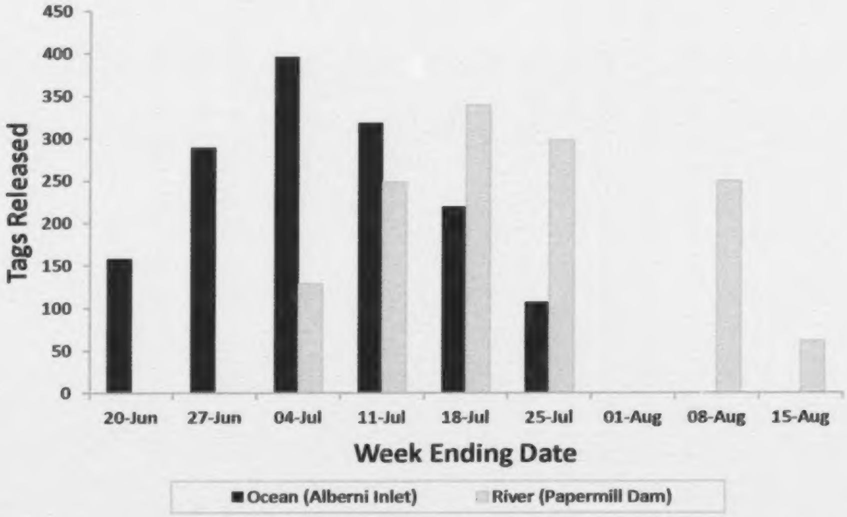

Figure 6. Summary of PIT tags applied by location and week for ocean-based tagging (aboard the Argent 1) and river-based tagging at the Papermill Dam (PMD) site, June-August 2010.

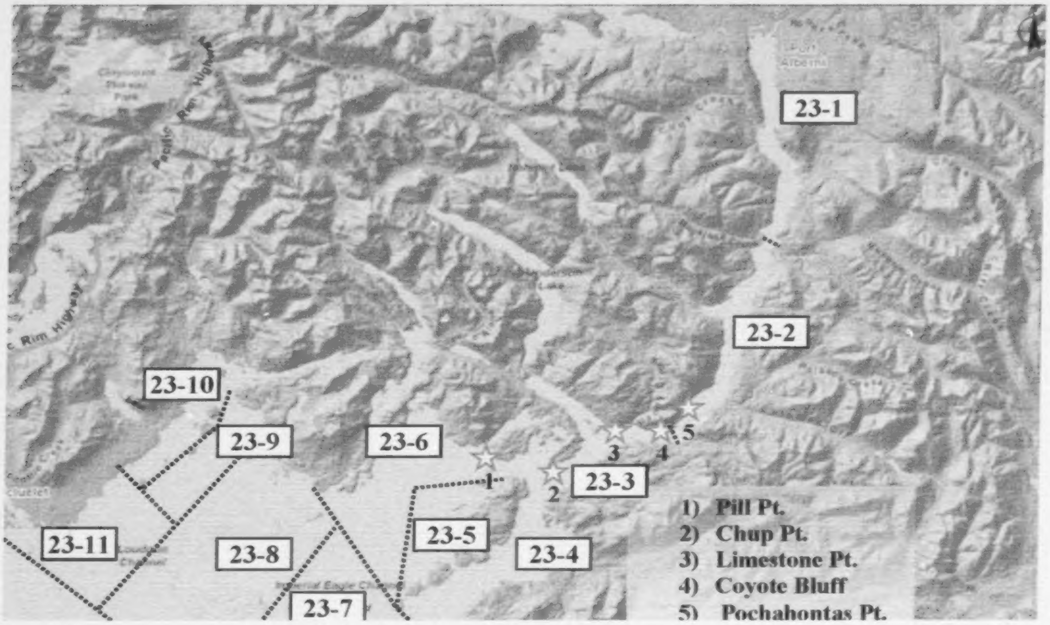
Port Alberni
Pacific Rim Highway
Rim Highway
23-1
23-2
23-3
23-4
23-5
23-6
23-7
23-8
23-9
23-10
23-11
1
2
3
4
5
1) Pill Pt.
2) Chup Pt.
3) Limestone Pt.
4) Coyote Bluff
5) Pochahontas Pt.

Figure 7. Map of Barkley Sound and Alberni Inlet indicating ocean test fishery set locations where PIT tags were applied to Sockeye aboard the vessel Argent 1. The approximate location of DFO statistical areas 23-1 through 23-11 are also indicated.

Figure 8. Seine capture at Papermill Dam of approximately 100 adult Sockeye.

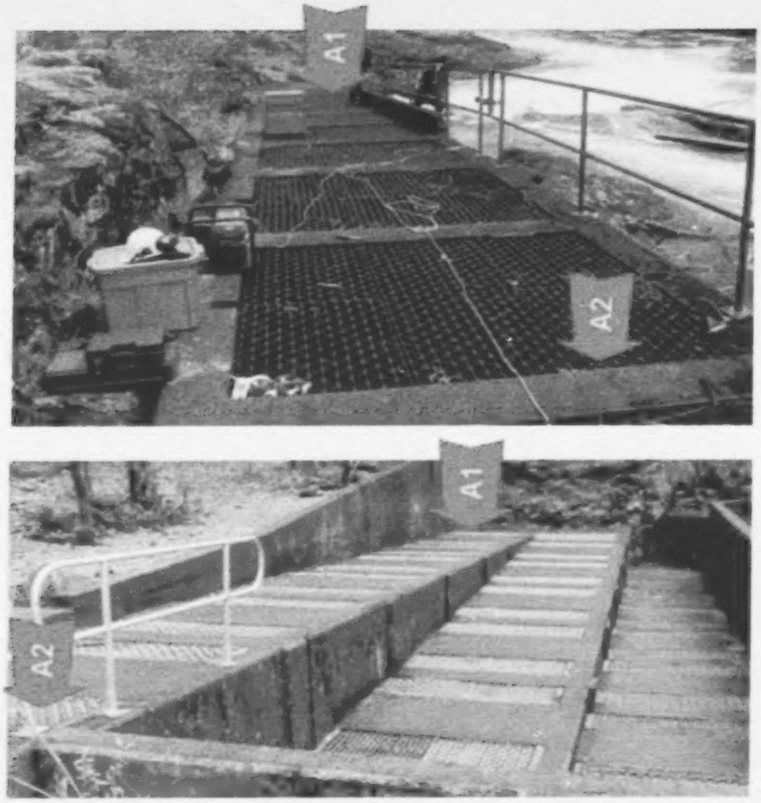

Figure 9. Sproat River fishway (top) and Stamp Falls fishway (bottom); arrows indicate location of antenna 1 (A1) and antenna 2 (A2) in each array.

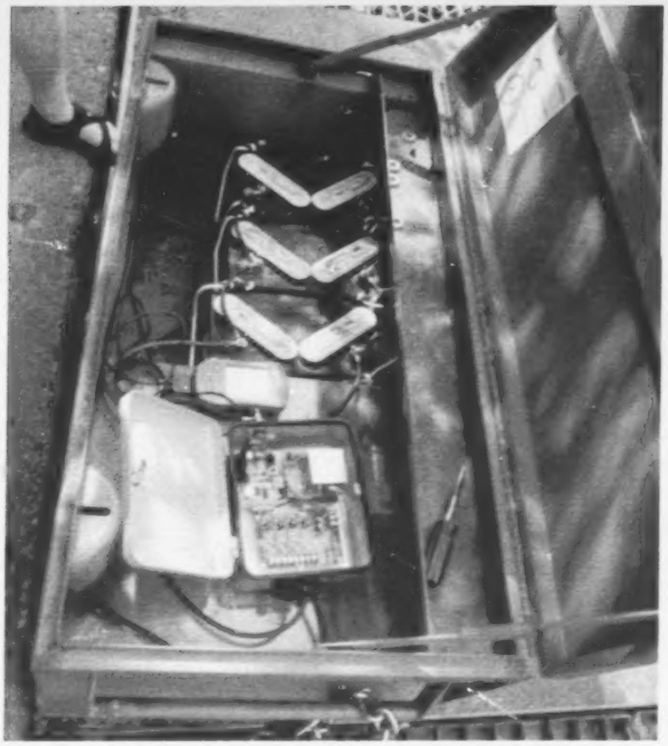

Figure 10. Metal container housing battery bank and RFID reader at Stamp Falls fishway (PDA connected).

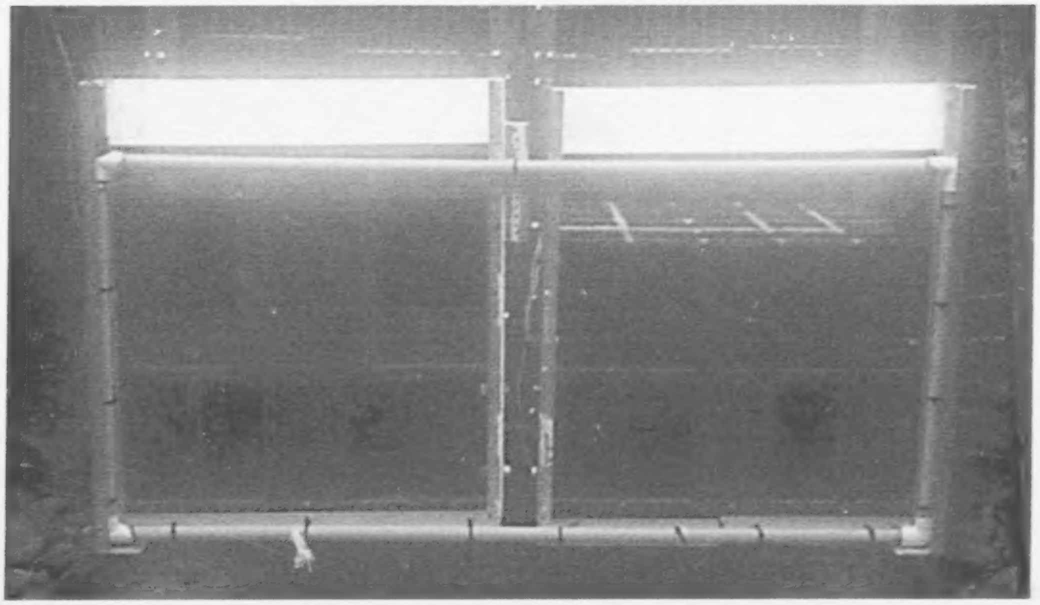

Figure 11. Underwater view of PIT antenna and PULSAR counter at Great Central Lake Dam.

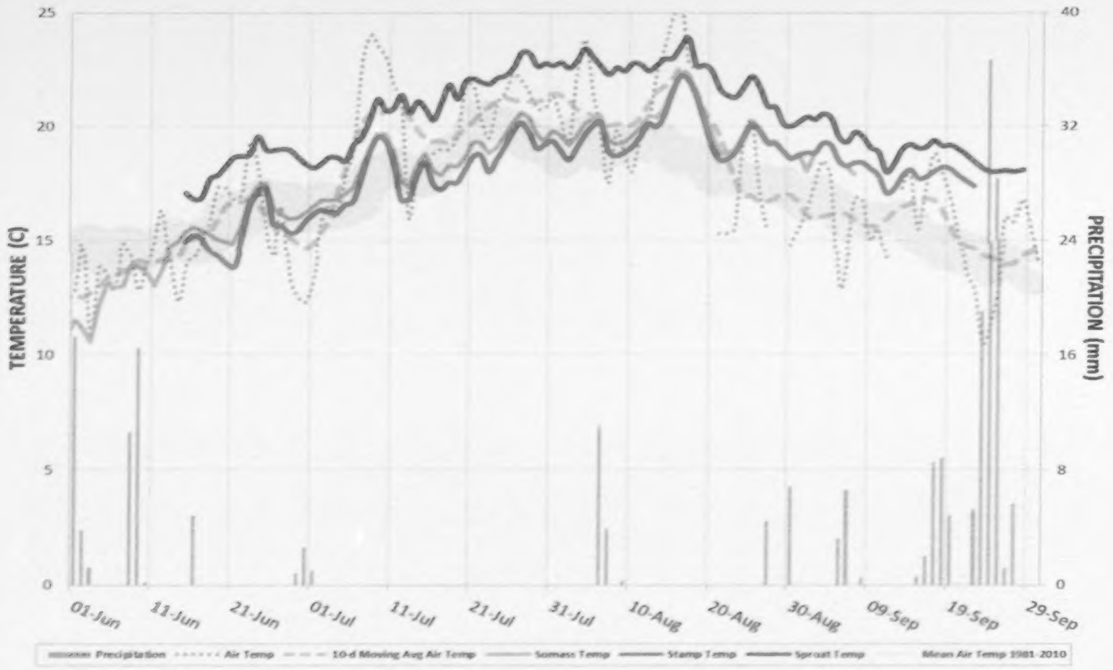

Figure 12. Environmental conditions in 2010. Total daily precipitation (blue bars), mean daily air temperature (red dotted line) from Robertson Creek Hatchery (including 10-day moving average air temperature, red dashed line; long-term daily mean air temperature (1981-2010; pink area)), and mean daily water temperatures from data loggers at Papermill Dam in the Somass River (green), Stamp River (blue), and Sproat River (purple).

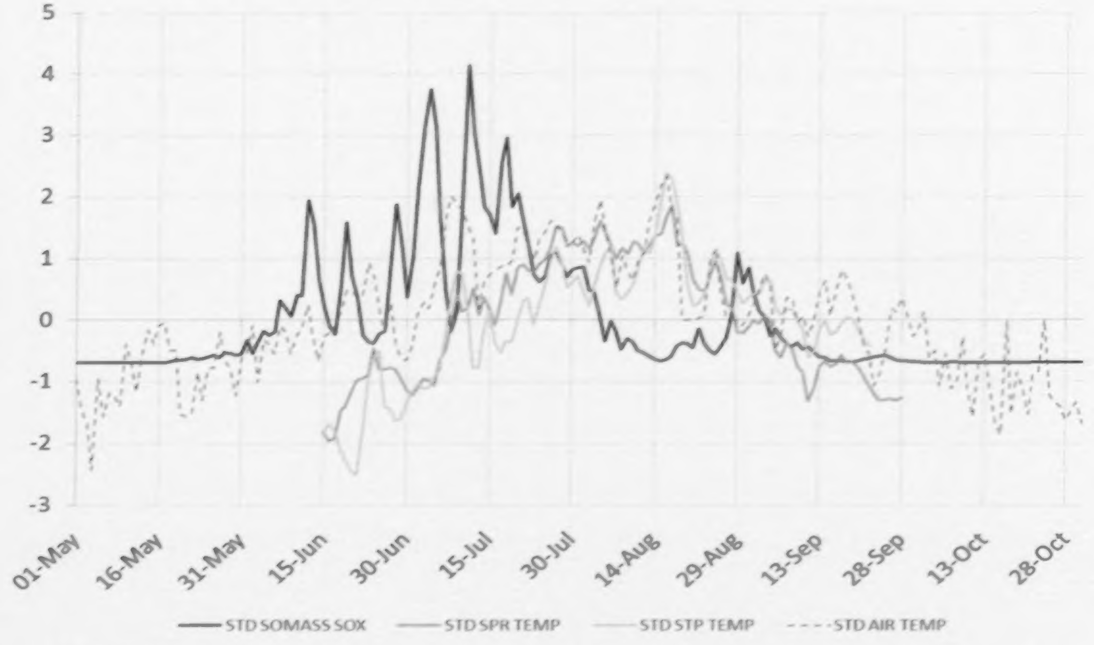

Figure 13. Standardized ($\mu=0$, $\sigma^2=1$) air and water temperature variates and total Somass Sockeye escapement, by date.

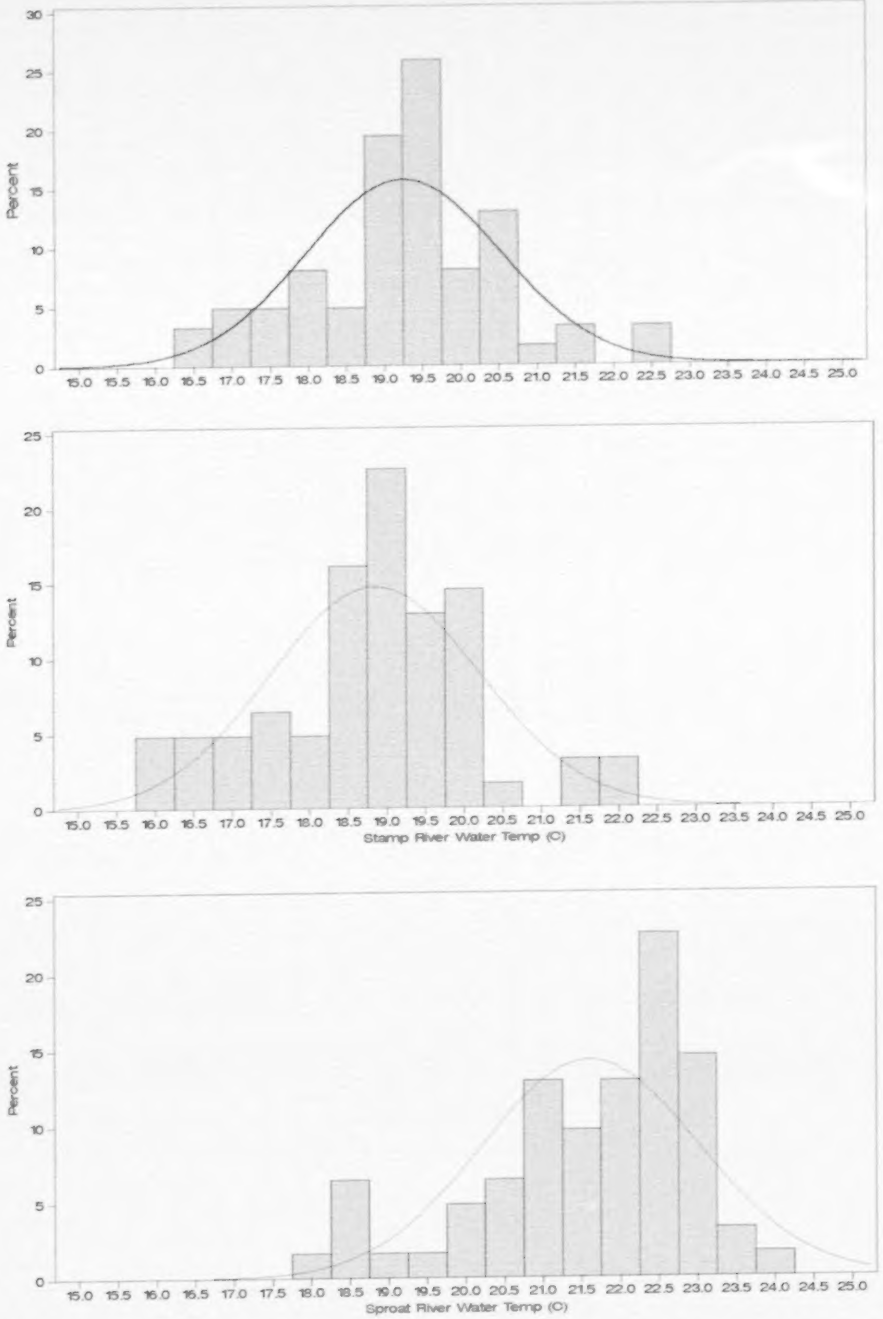

Figure 14. Frequency distribution of mean daily water temperatures from Hobo data loggers at Papermill Dam in the Somass River (top), Stamp River (middle), and Sproat River (bottom) above the Stamp/Sproat confluence, indicating minimum, modal, and maximum temperatures in July-August, 2010.

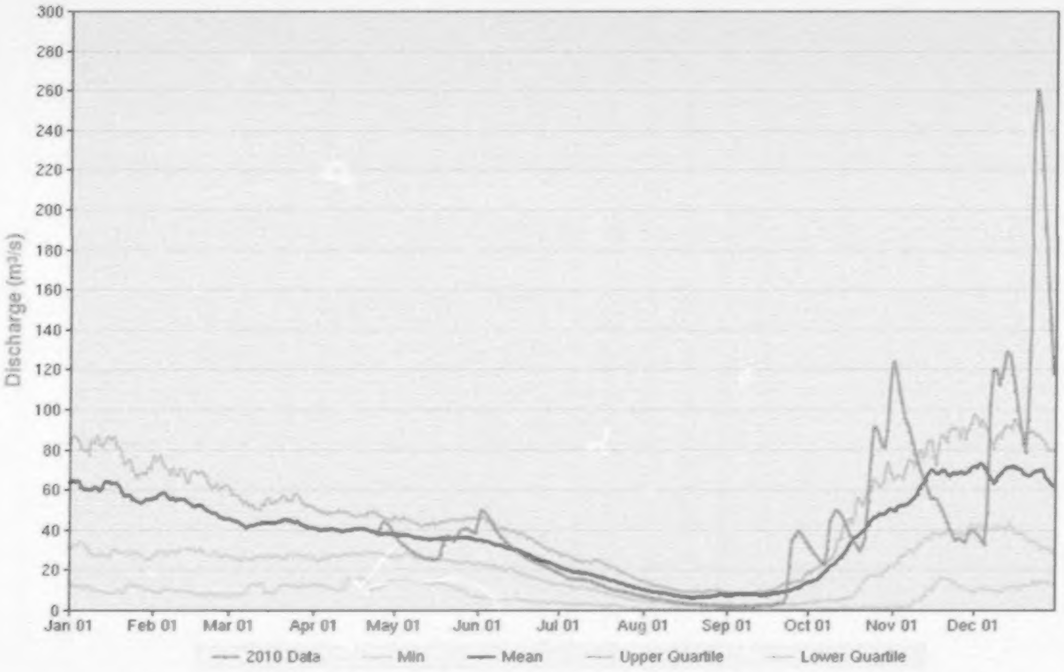

Figure 15. Mean daily Sproat River discharge[61], 2010 (red). Daily discharge levels for the Sockeye migration period (June-September) were low but above the lower quartile (i.e., within the 25th – 50th percentile) of historic flows. Min, mean, and quartile statistics based on data from 1913 to present. Max flows were omitted for readability – 2010 discharge did not exceed historic maximums at any time. Source: Environment Canada (http://wateroffice.ec.gc.ca/mainmenu/historical_data_index_e.html).

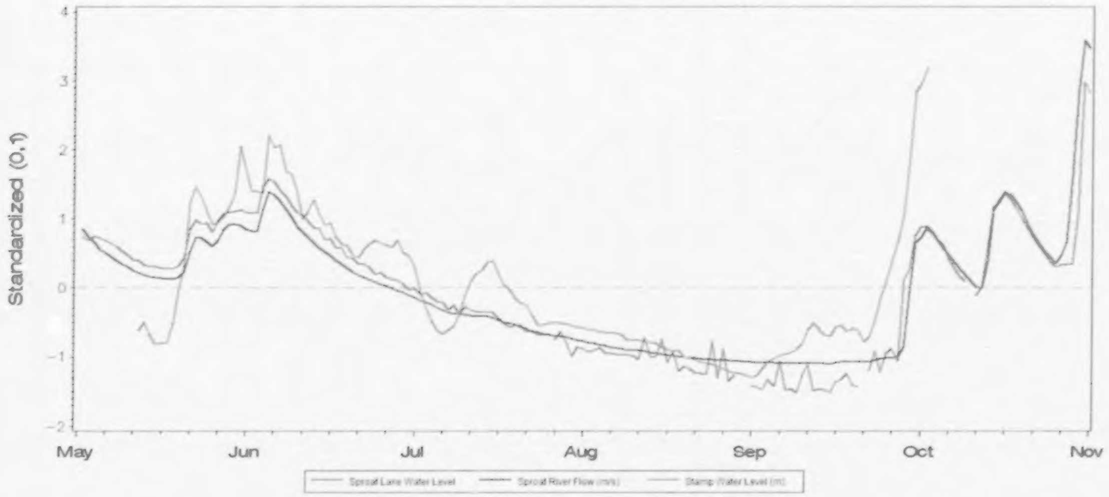

Figure 16. Mean daily water levels (standardized to μ=0, σ²=1) from the Stamp River (red), Sproat Lake (green), and from the Sproat River (blue).

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[61] Sproat River water levels in 2010 not available from Environment Canada.

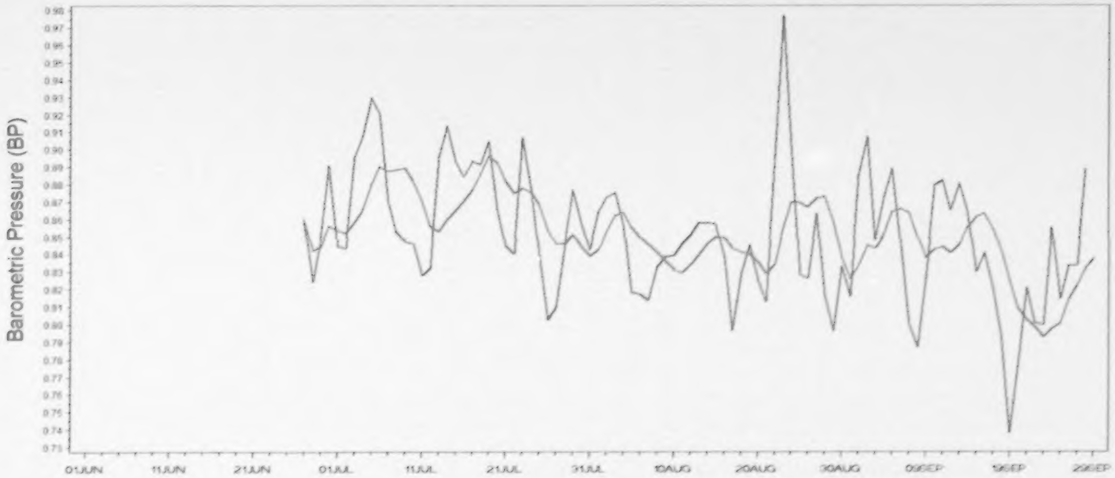


Figure 17. Mean daily barometric pressure (blue) and 7-day backward moving average barometric pressure (red), measured near Great Central Lake, June 23 – September 30, 2011.

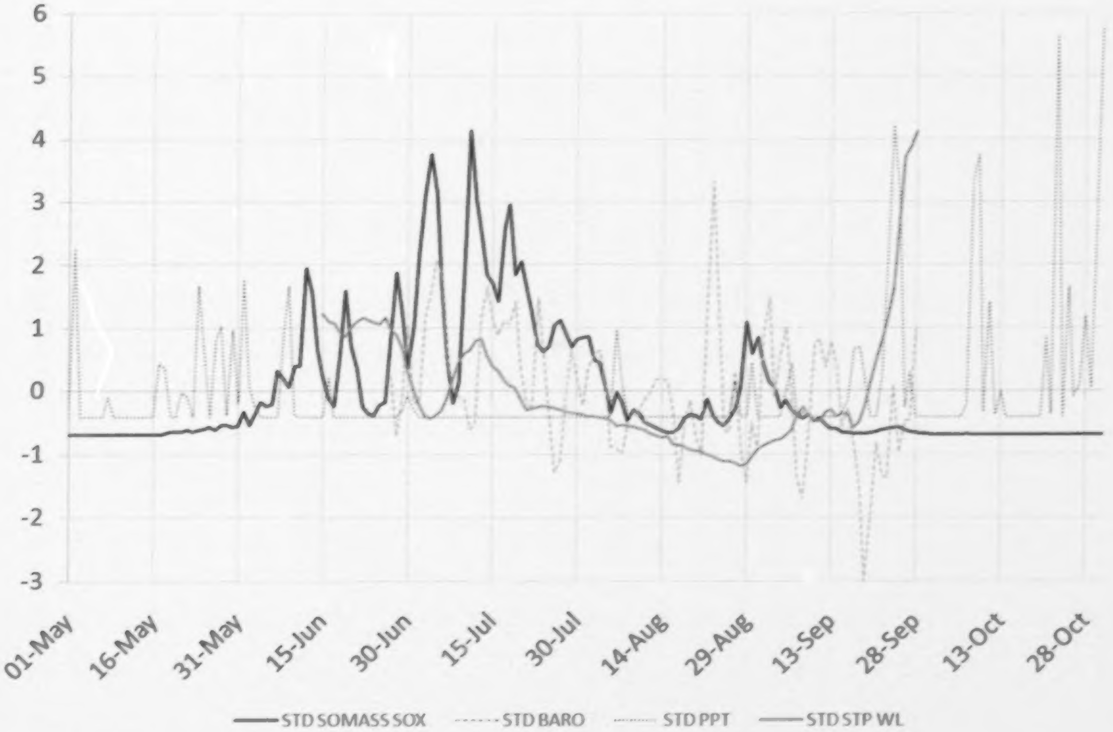


Figure 18. Standardized ($\mu=0$, $\sigma^2=1$) environmental variates and total Somass Sockeye escapement, by date. Air and water temperature variates (top) and barometric pressure, precipitation, and Stamp River water level (bottom).

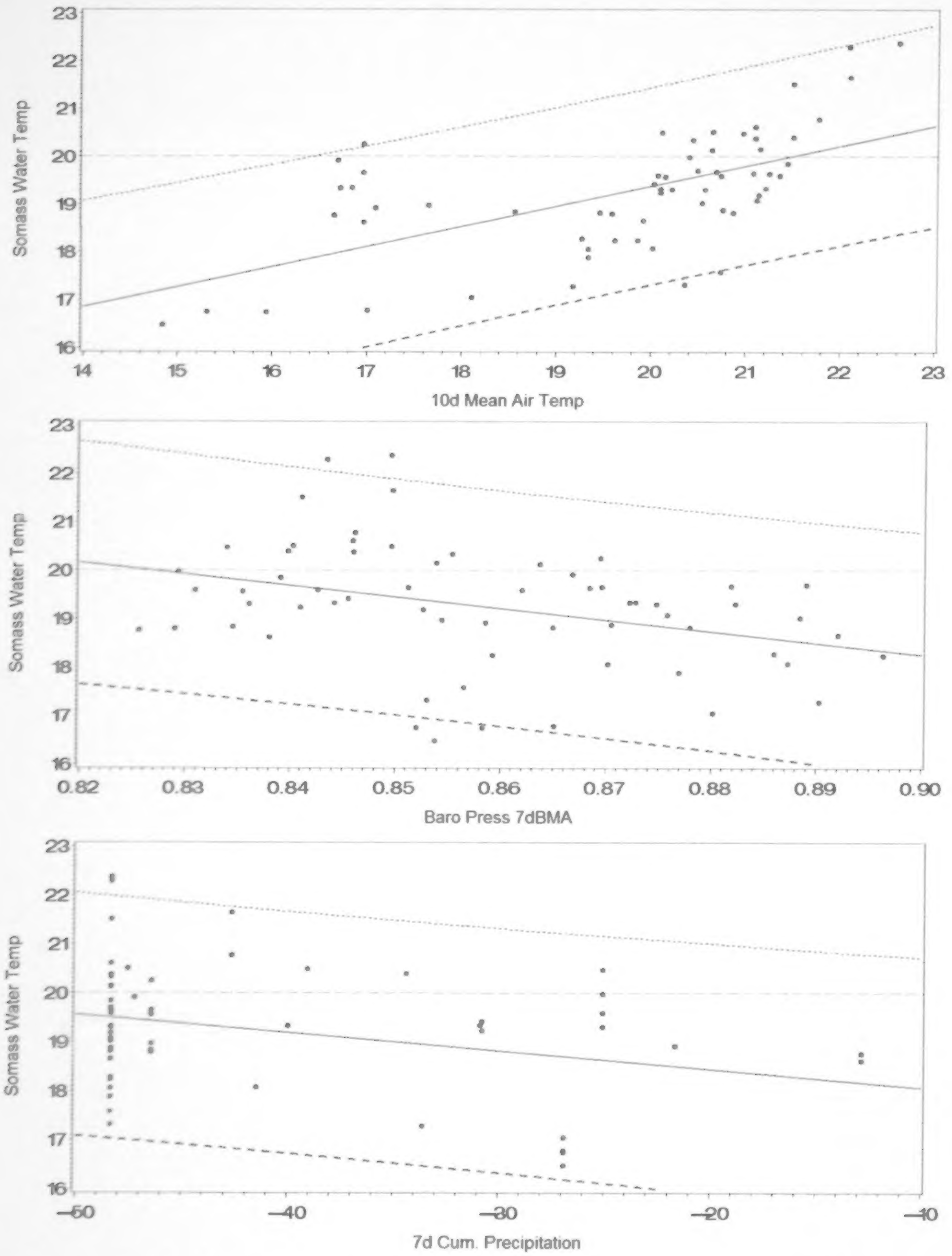


Figure 19. Somass mean daily water temperature as a function of 10-d moving average air temperature (top), 7-d moving average barometric pressure (middle), and 7-d cumulative total precipitation (log-transformed, bottom). All relationships significantly correlated ($P < 0.001$).

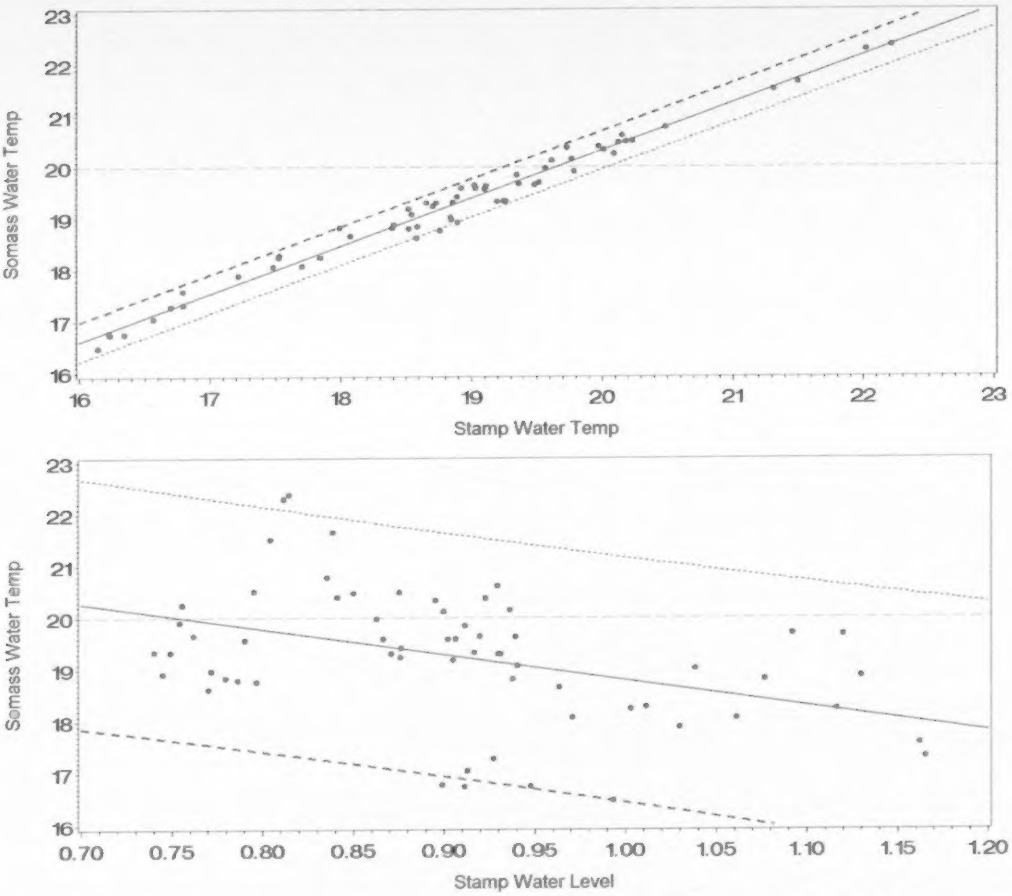


Figure 20. Somass mean daily water temperature as a function of Stamp River water temperature (top), and Stamp River water level (bottom). All relationships significantly correlated ($P < 0.001$).

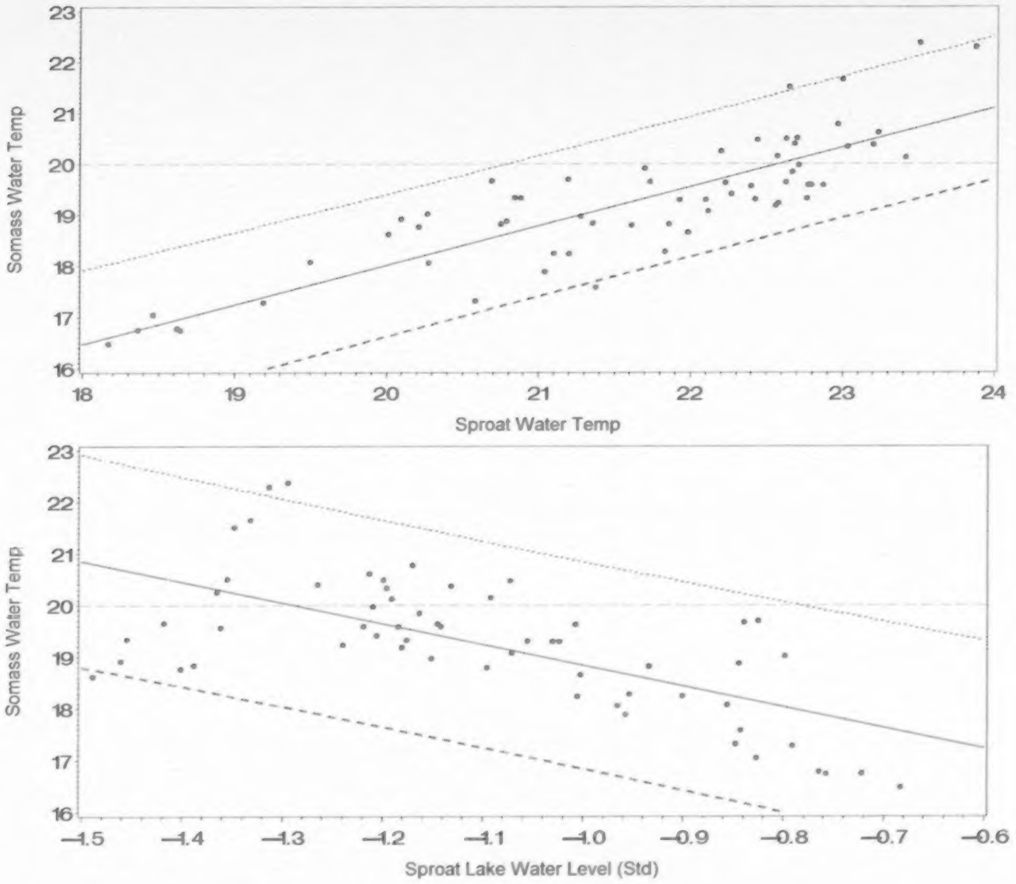


Figure 21. Somass mean daily water temperature as a function of Sproat River water temperature (top), Sproat water level (bottom). All relationships significantly correlated ($P < 0.001$).

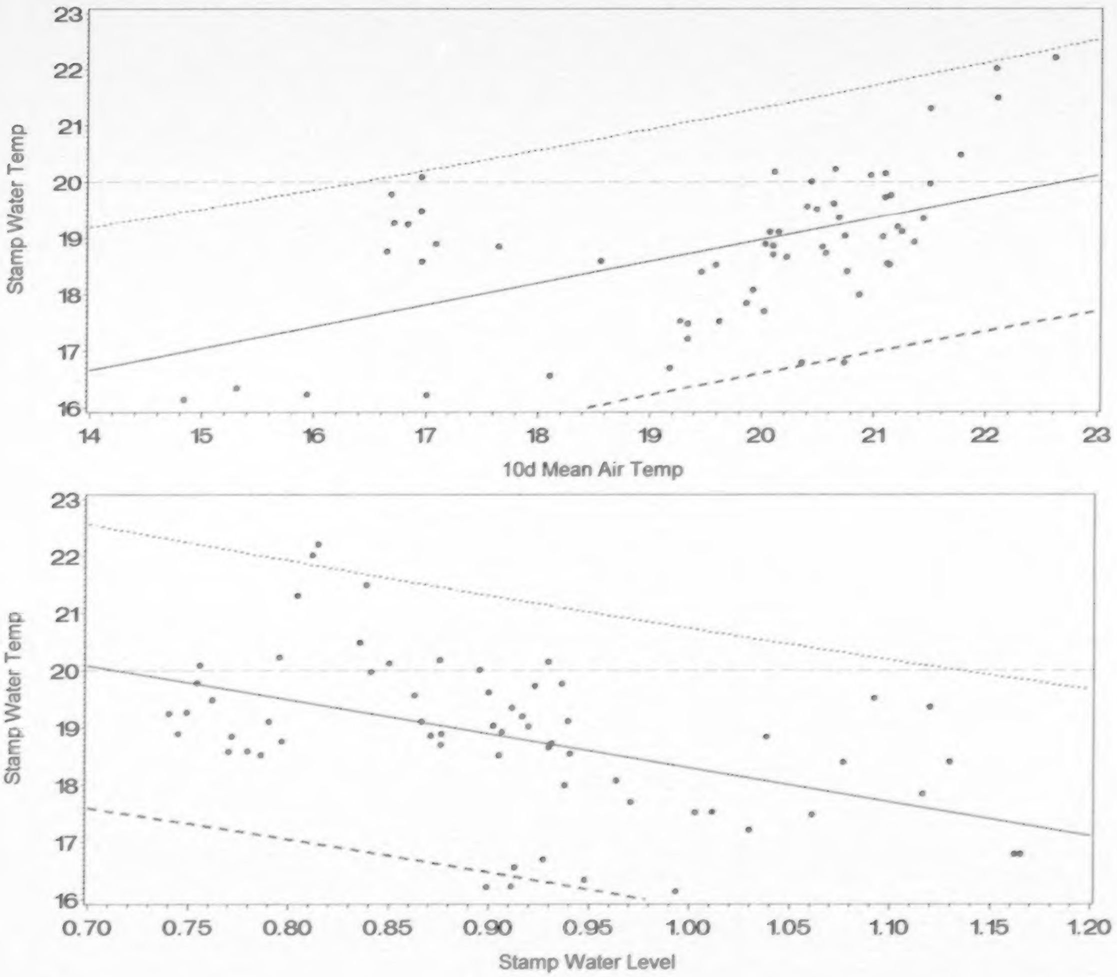


Figure 22. Stamp River mean daily water temperature as a function of 10-d moving average air temperature (top), and Stamp River water level (bottom). All relationships significantly correlated ($P < 0.001$).

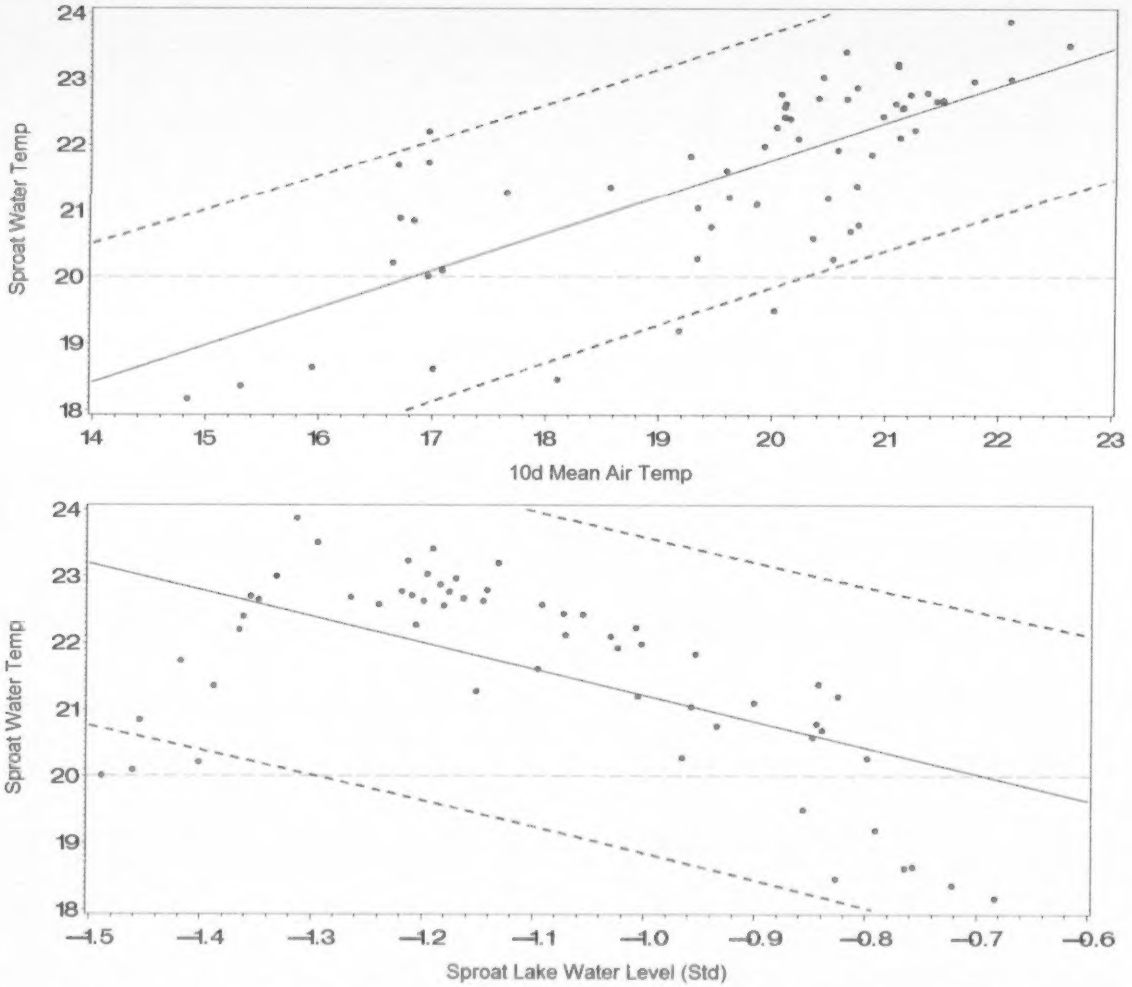


Figure 23. Sproat River mean daily water temperature as a function of 10-d moving average air temperature (top), Sproat water level (log-transformed, bottom). All relationships significantly correlated ($P < 0.001$).

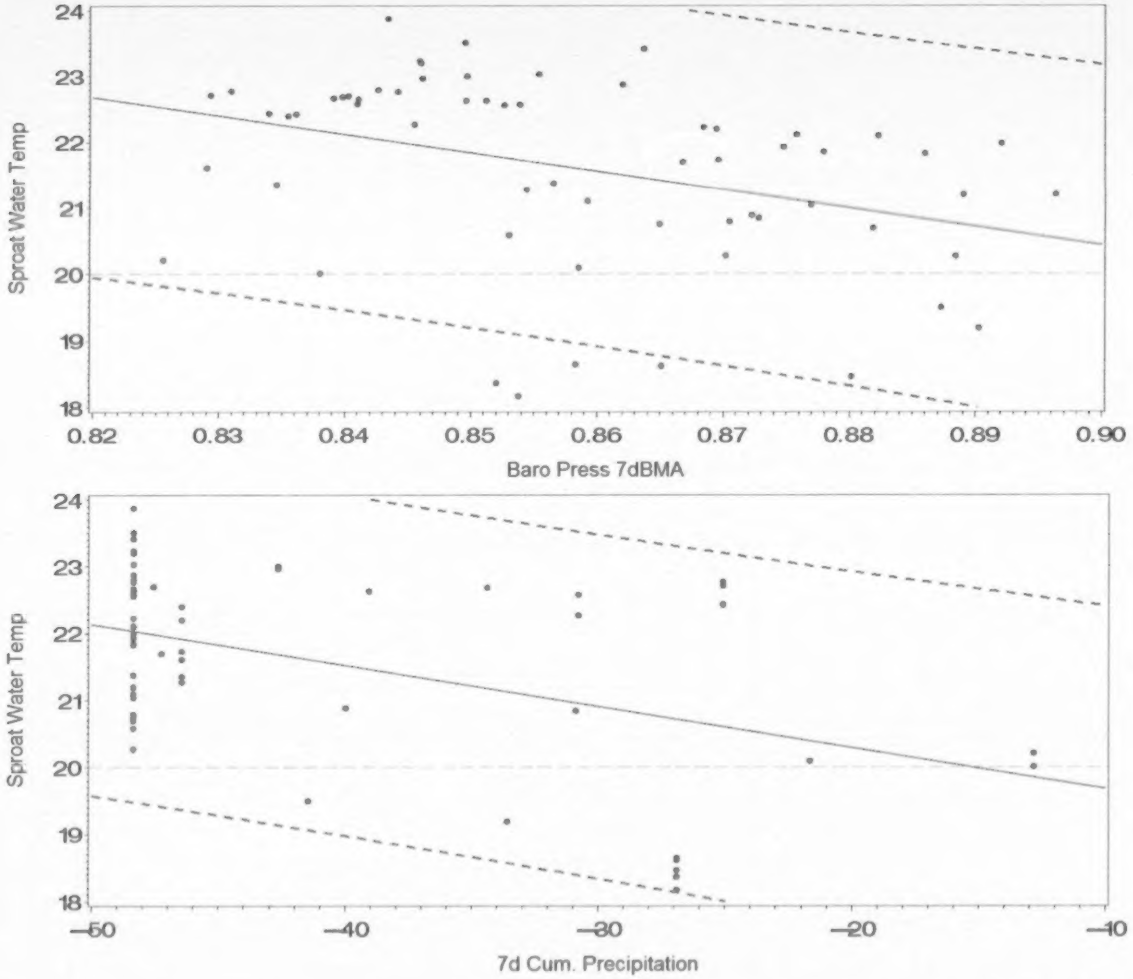


Figure 24. Sproat River mean daily water temperature as a function of 7-d moving average barometric pressure (top), and 7-d cumulative total precipitation (log-transformed, bottom). All relationships significantly correlated ($P < 0.001$).

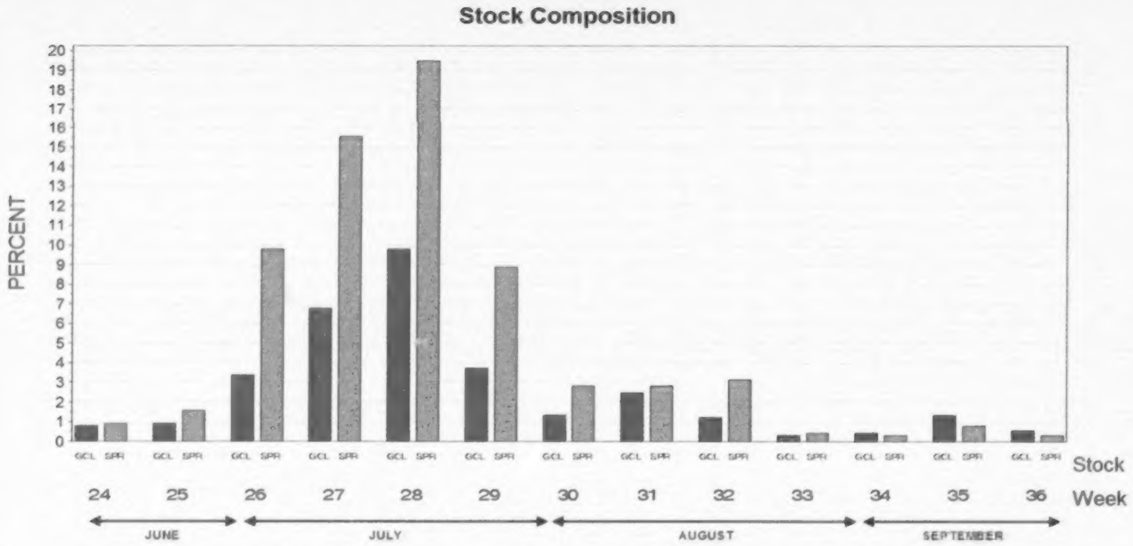


Figure 25. Weekly PIT tag stock composition as a percent of total tags detected at Stamp (GCL stock) and Sproat fishways. Overall stock composition based on all PIT tags: 67% Sproat and 33% GCL.

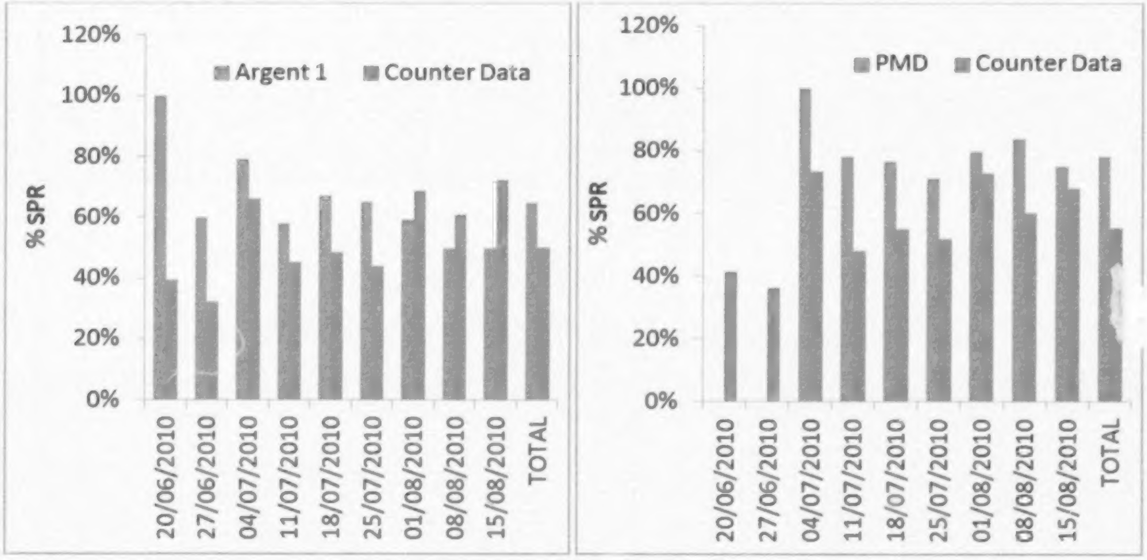


Figure 26. Weekly percentage of tagged to untagged sockeye tallied at the Sproat fishway (vs the Stamp fishway) for ocean-tagged fish (left) and river-tagged fish (right). Overall stock composition based on ocean-based PIT tags: 61% Sproat; and based on in-river tagging operations: 73% Sproat.

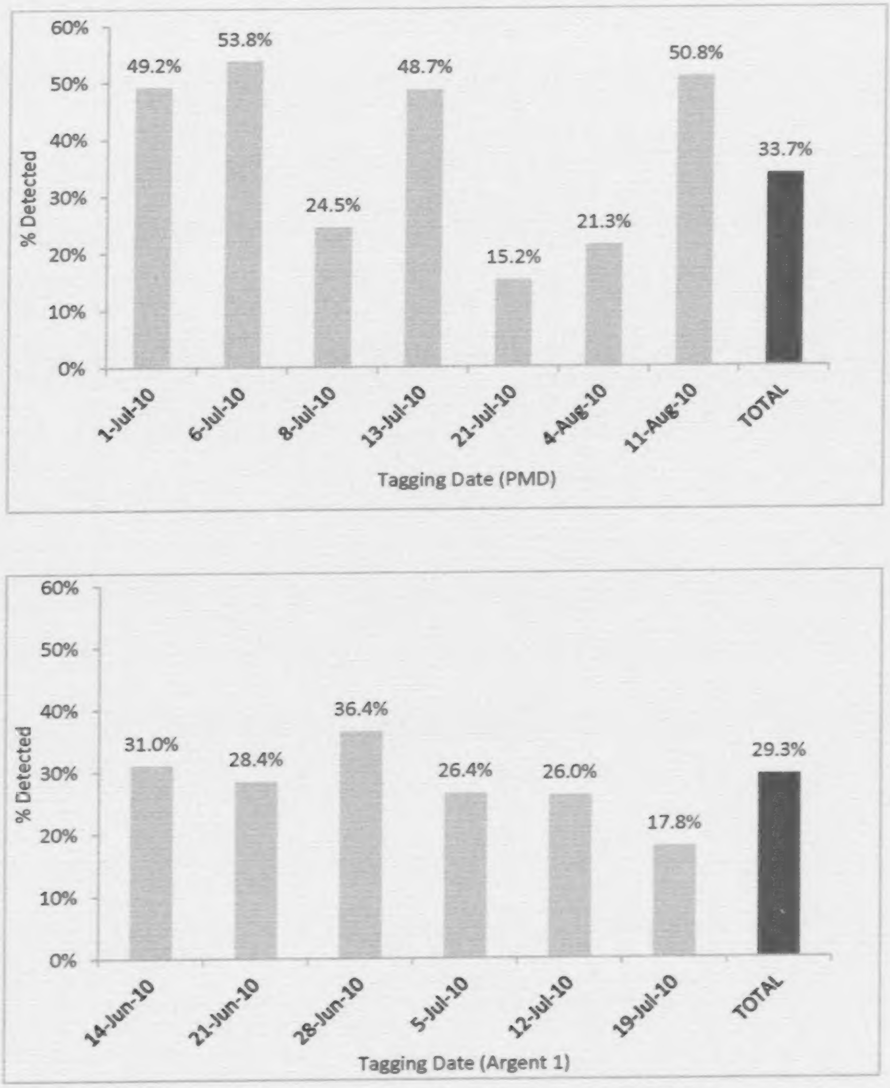


Figure 27. Weekly percentage of PIT tags detected in the Somass watershed for river-tagged fish (top) and ocean-tagged fish (bottom). Overall percentages in blue.

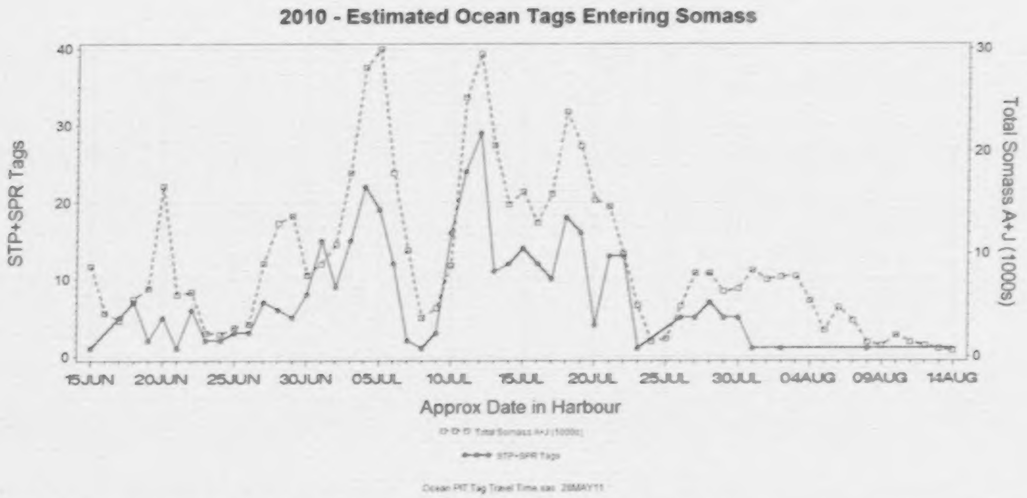


Figure 28. Total Somass Sockeye (adults + jacks, thousands) estimates based on DFO fish counters (dashed green line) and combined Stamp and Sproat tag detections (blue solid line) aligned by approximate date of passage through Alberni Harbour.

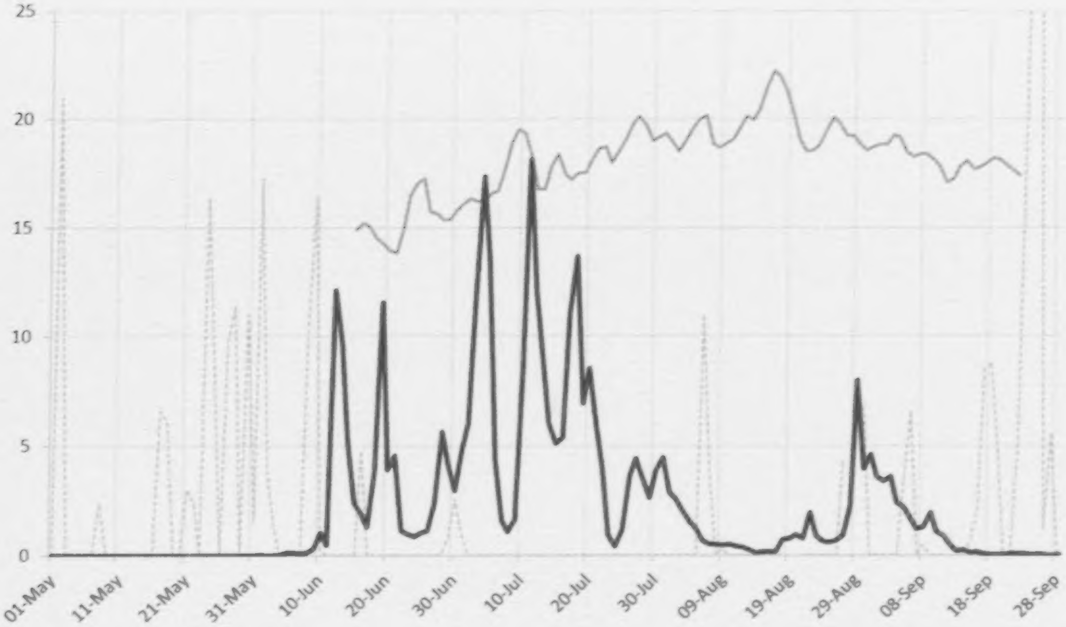


Figure 29. Great Central Lake Sockeye migrants (thousands, counted at GCL fishway, lagged back four days to Somass Papermill site), Stamp/Somass water temperature (°C, solid red), and regional precipitation (mm, dashed blue).

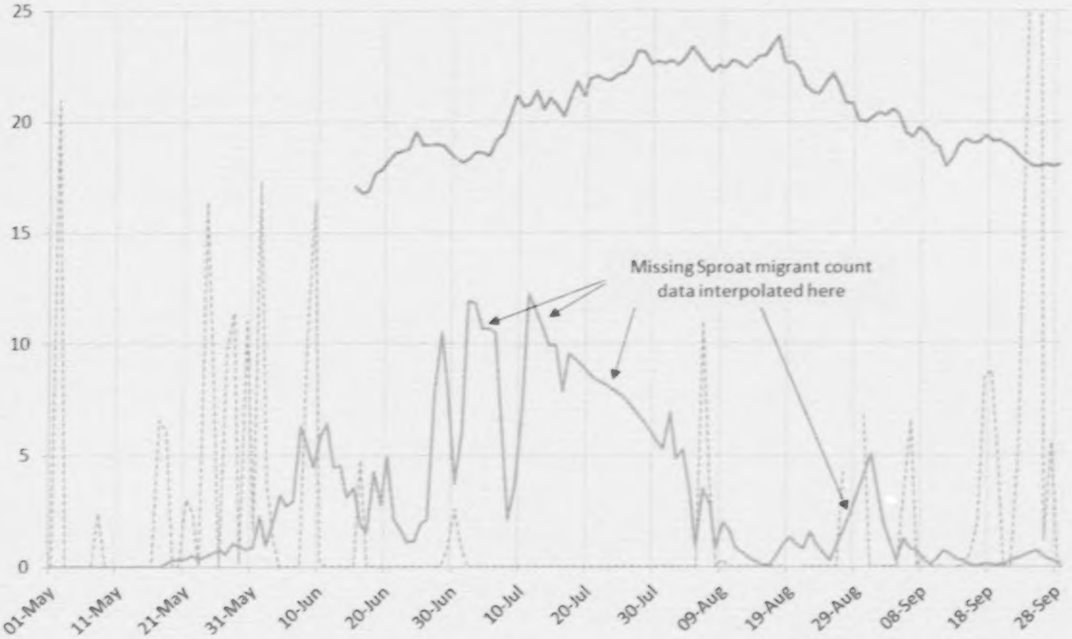


Figure 30. Sproat Lake Sockeye migrants (thousands, counted at Sproat fishway, lagged back two days to Somass Papermill site), Sproat River water temperature (°C, solid red), and regional precipitation (mm, dashed blue). Fish counter failures resulting in missing daily estimates (interpolated here) obscure migration patterns between 04-July and 03-Aug.

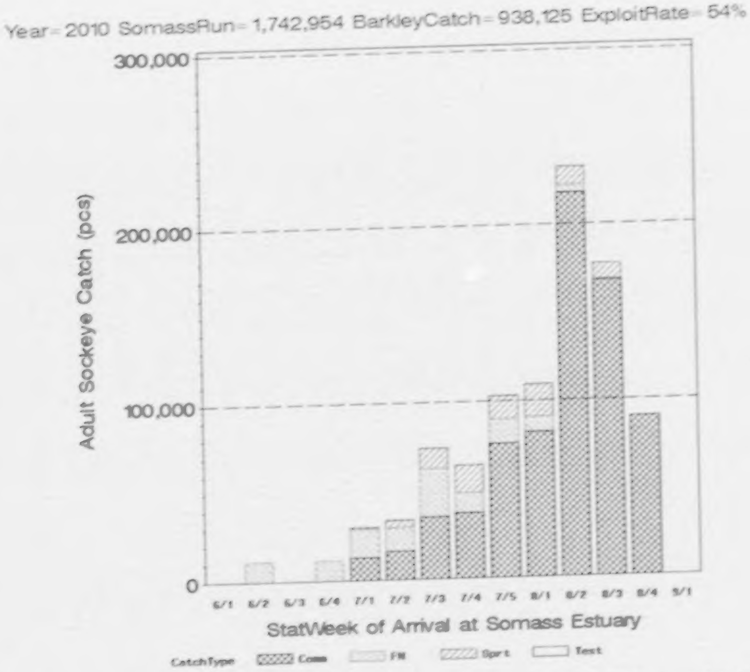


Figure 31. Weekly total Sockeye catch by fishery lagged forward in time to the mouth of the Somass (as if they had not tbeen caught). Weekly total harvest across all fisheries as a percentage of weekly total run ranged from 0-25% in June, to 30-50% in July, and 80-90% in August.

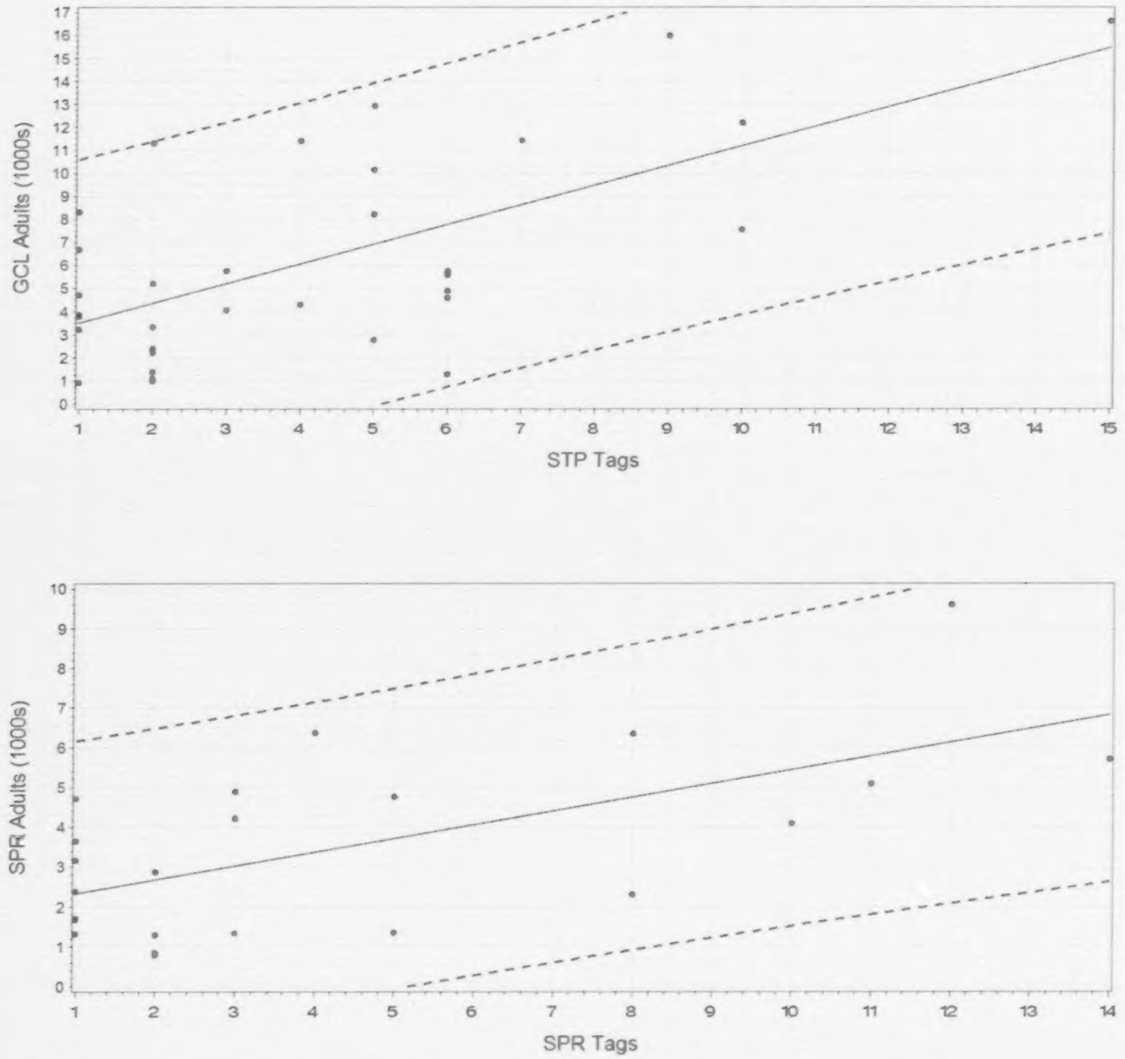


Figure 32. Somass stock Sockeye (adults, thousands) estimates based on DFO fish counters as a function of tag detections (Stamp, top: $r_S = 0.59$, $P < 0.05$, $n = 38$; Sproat, bottom, $r_S = 0.56$, $P < 0.05$, $n = 23$).

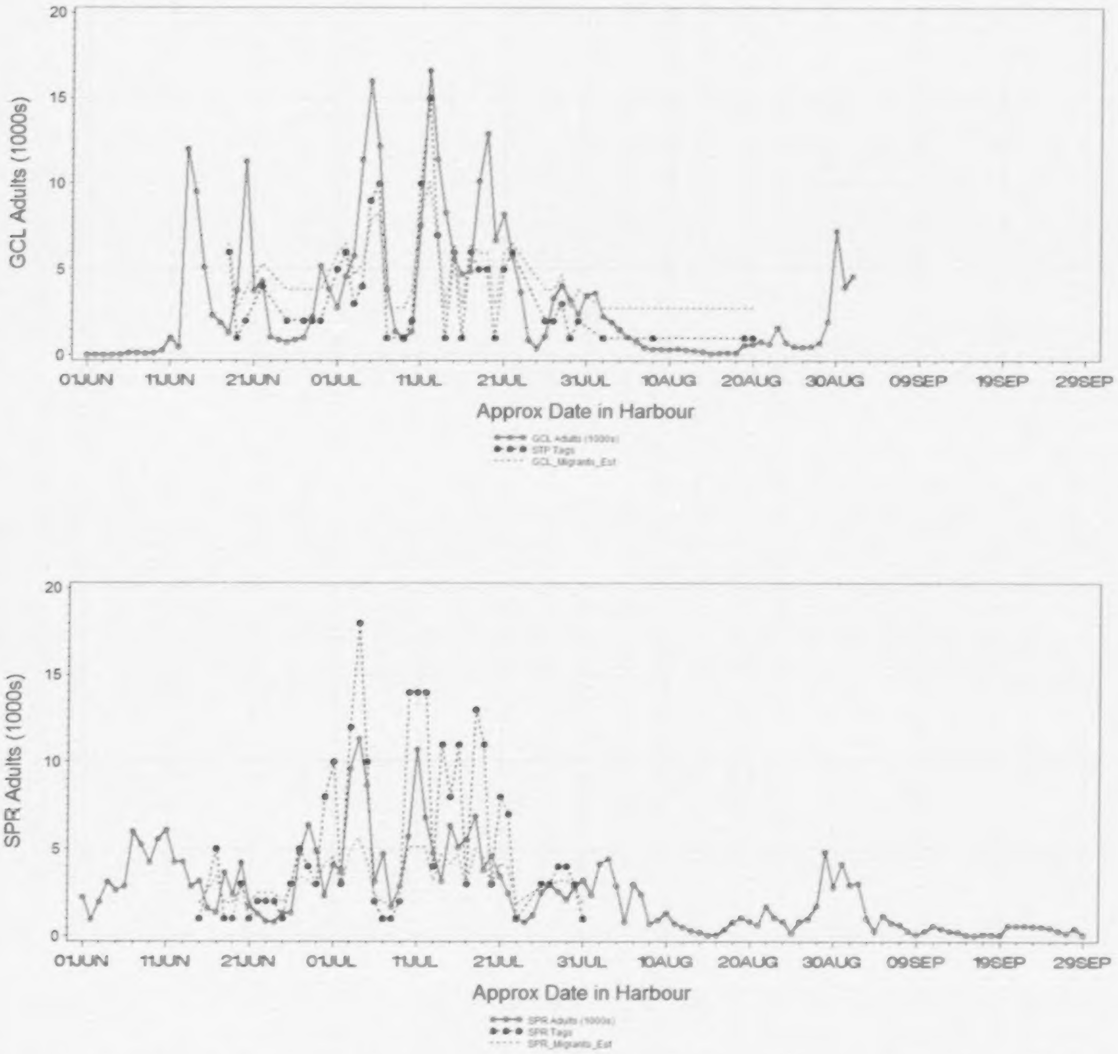


Figure 33. Somass stock Sockeye (adults, thousands) estimates based on DFO fish counters (solid blue line), tag detections (dotted blue line), and estimated counts (thousands) based on tags-to-migrants relationships (dotted green line) for Great Central Lake Sockeye (top), and Sproat Lake Sockeye (bottom).

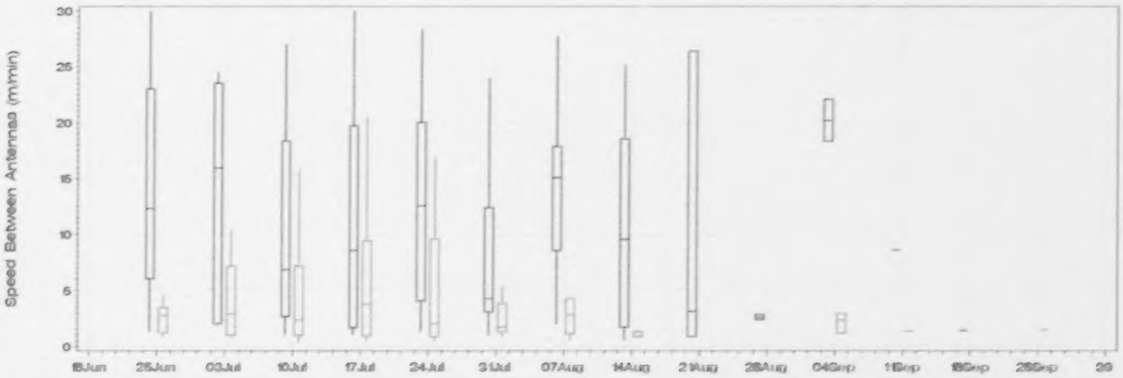


Figure 34. Median and range of individual fish swim speeds (meters per minute) transiting between antennas in the Sproat (red) and Stamp (blue) fishways, by week ending date. Boxplots offset by one day for readability.

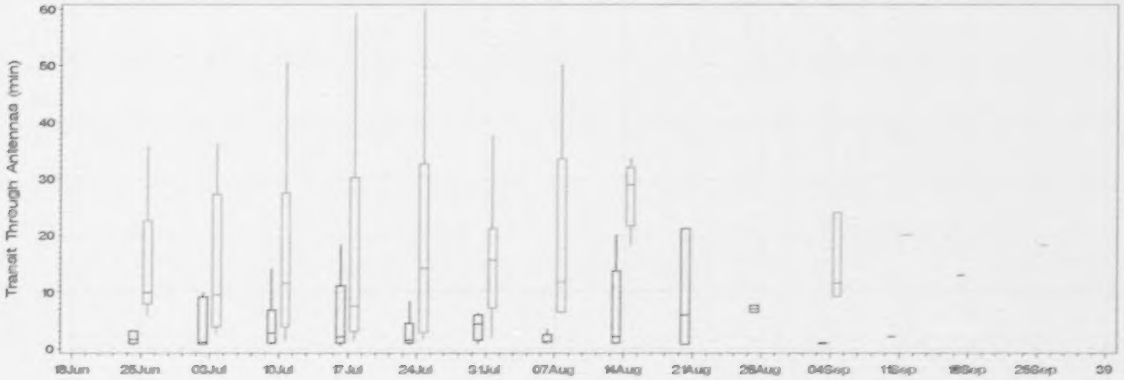


Figure 35. Median and range of individual fish transit times (total minutes) between antennas in the Sproat (red) and Stamp (blue) fishways, by week ending date. Boxplots offset by one day for readability.

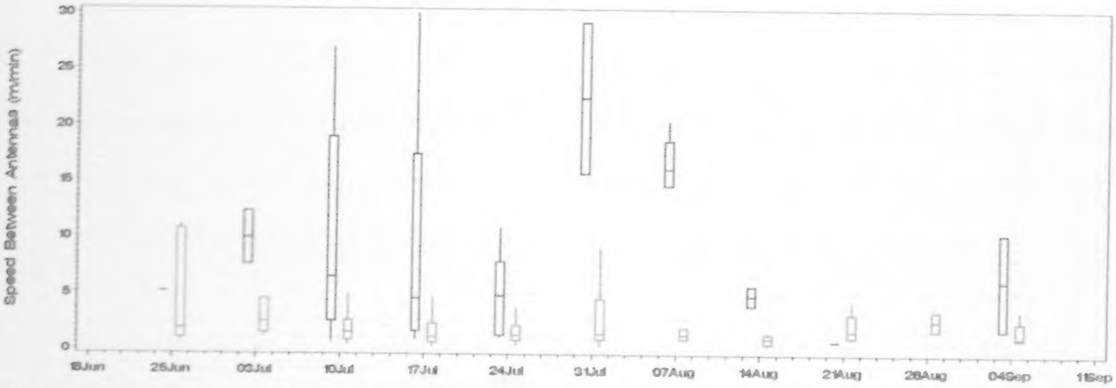


Figure 36. Median and range of fall-back fish swim speeds (meters per minute) transiting between antennas in the Sproat (red) and Stamp (blue) fishways, by week ending date. Restricted to fish that were detected at Antenna #2 only once. Boxplots offset by one day for readability.

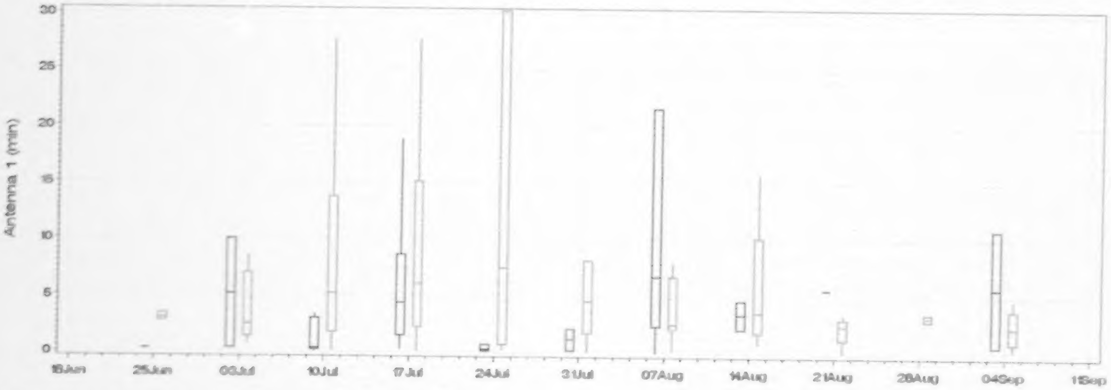


Figure 37. Median and range of fall-back fish transit times (minutes) between first and last tag detection at the lower antenna (#1) in the Sproat (red) and Stamp (blue) fishways. Restricted to fish that were detected at Antenna #2 only once. Boxplots offset by one day for readability.

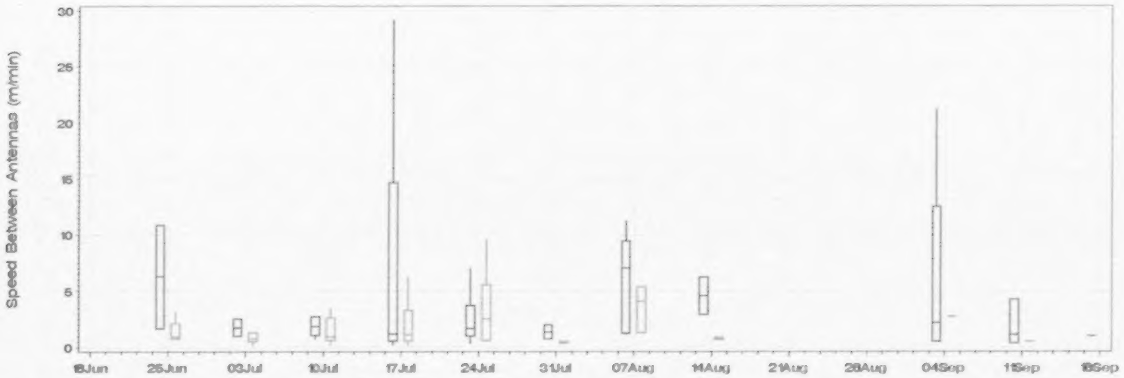


Figure 38. Median and range of fall-back fish swim speeds (meters per minute) transiting between antennas in the Sproat (red) and Stamp (blue) fishways, by week ending date. Restricted to fish that were detected at Antenna #1 only once but Antenna #2 multiple times. Boxplots offset by one day for readability.

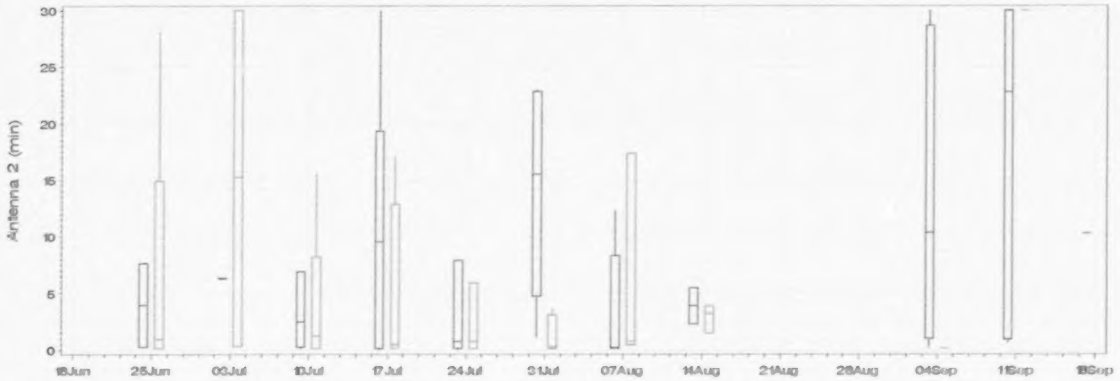


Figure 39. Median and range of fall-back fish transit times (minutes) between first and last tag detection at the upper antenna (#2) in the Sproat (red) and Stamp (blue) fishways. Restricted to fish that were detected at Antenna #1 only once but Antenna #2 multiple times. Boxplots offset by one day for readability.

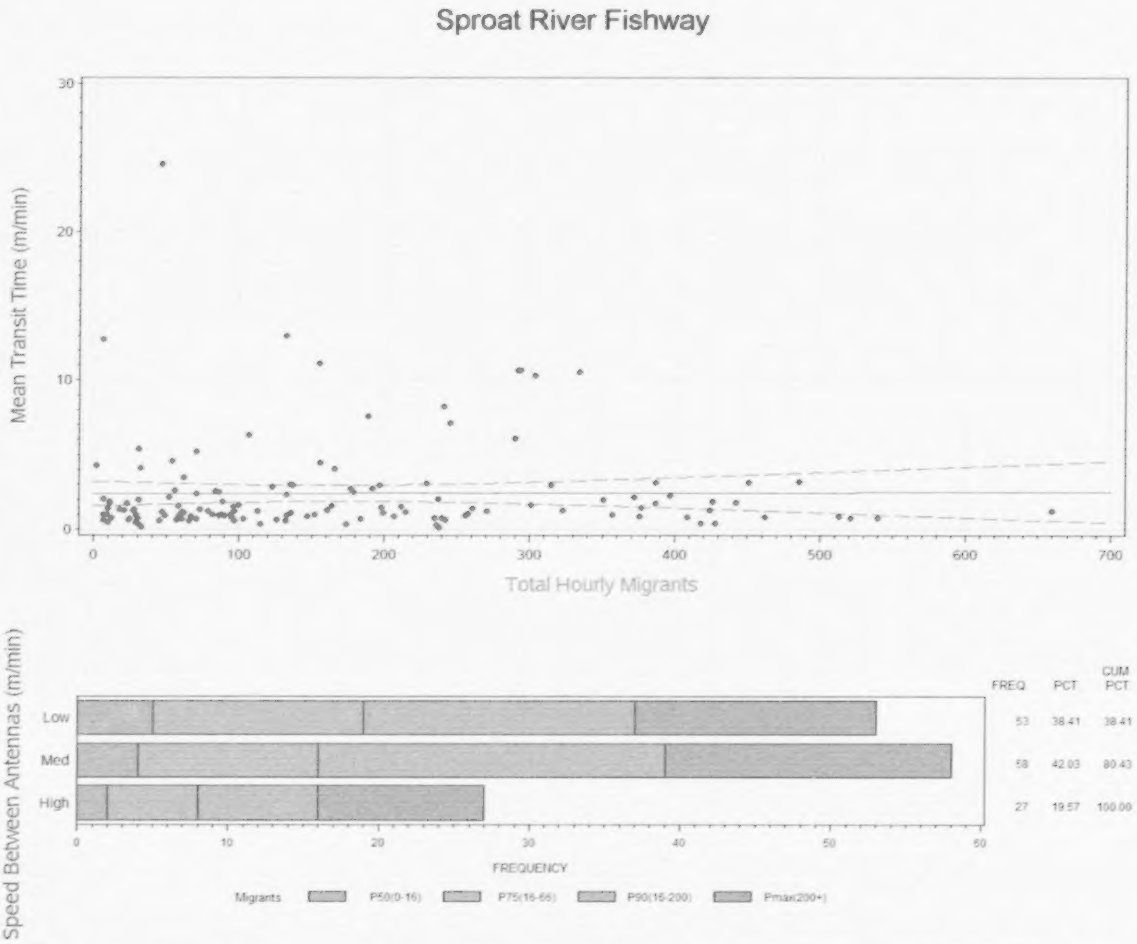
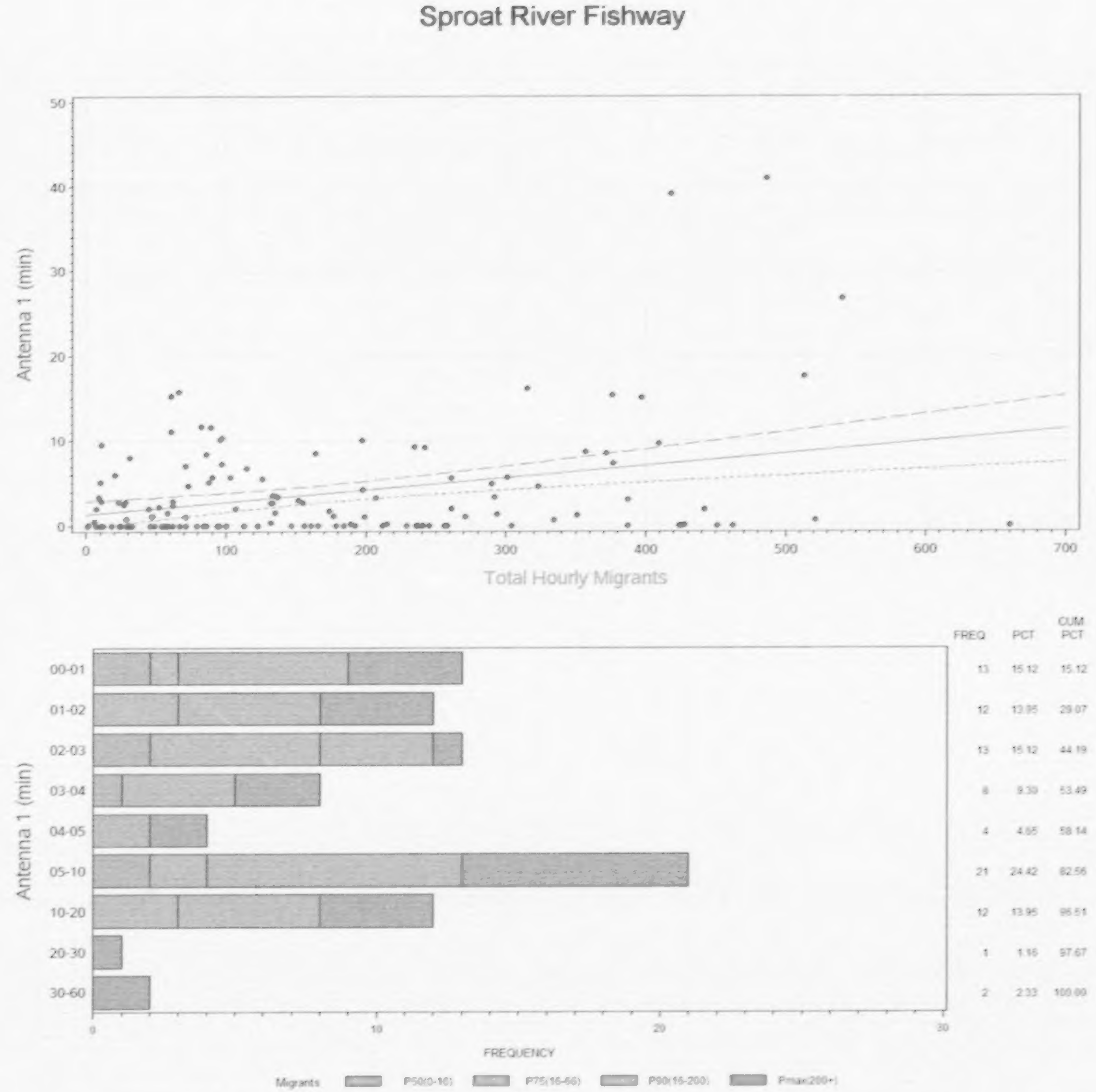


Figure 40. Transit rates (meters per minute) for PIT-tagged Sockeye in the Sproat fishway as a function of concurrent hourly migrant numbers (parametric linear regression (top) and non-parametric frequency analysis (bottom); P > 0.50, n=138).



Sproat River Fishway

Figure 41. Mean transit time (minutes) for PIT-tagged Sockeye passing antenna 1 to enter the Sproat fishway, as a function of concurrent hourly migrant density (parametric linear regression (top): $Y = 1.32 + 0.014 * X$; $r^2 = 0.10$; $P < .001$; $n = 138$; and non-parametric frequency analysis ($P > 0.50$, $n = 138$).

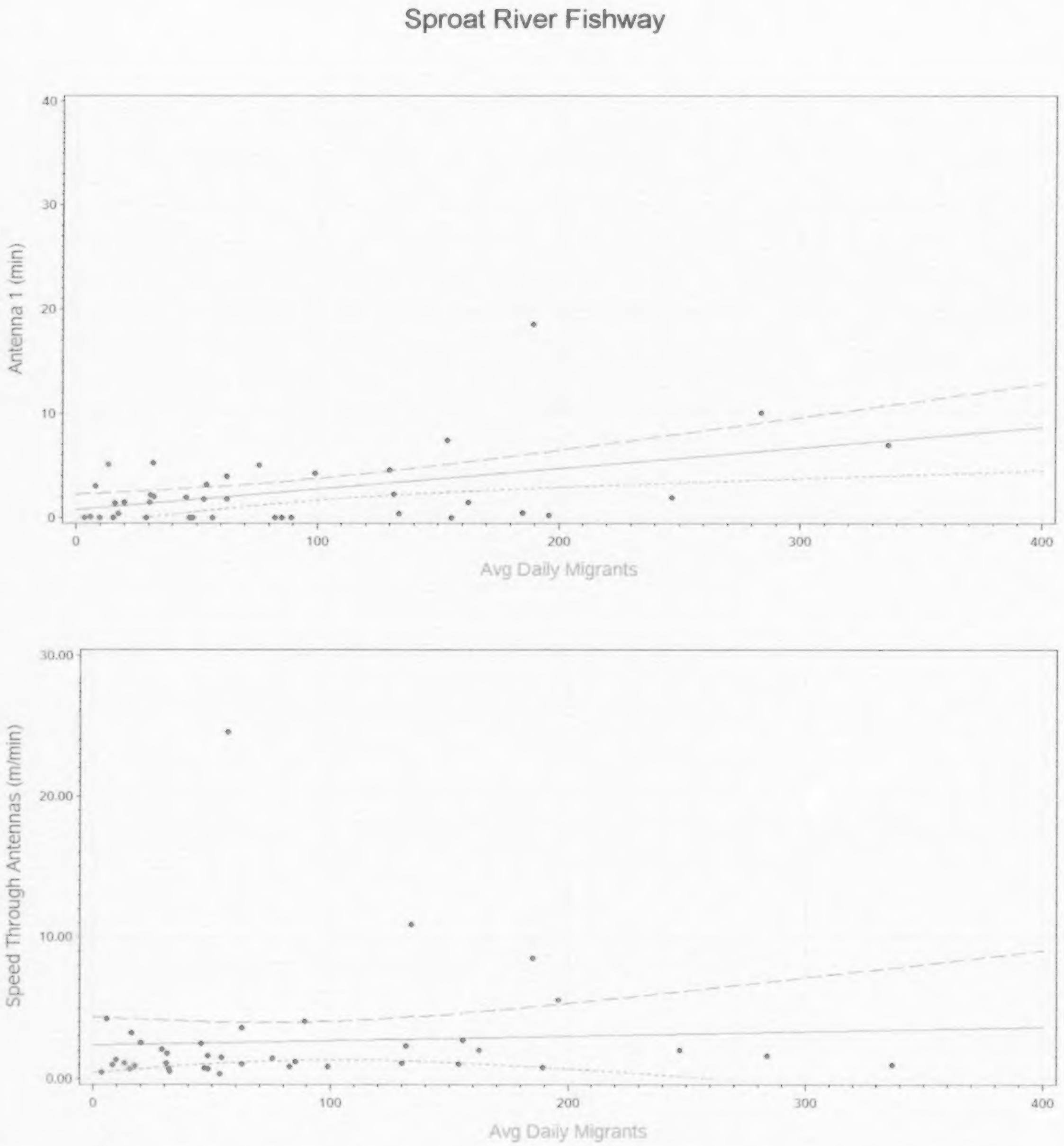


Figure 42. Mean daily PIT tag duration (minutes) at antenna #1 (top) and fishway transit rates (meters per minute) in the Sproat fishway as a function of daily mean number of migrants (r_s ~ = 0.30; $P > 0.05$; $n = 40$).

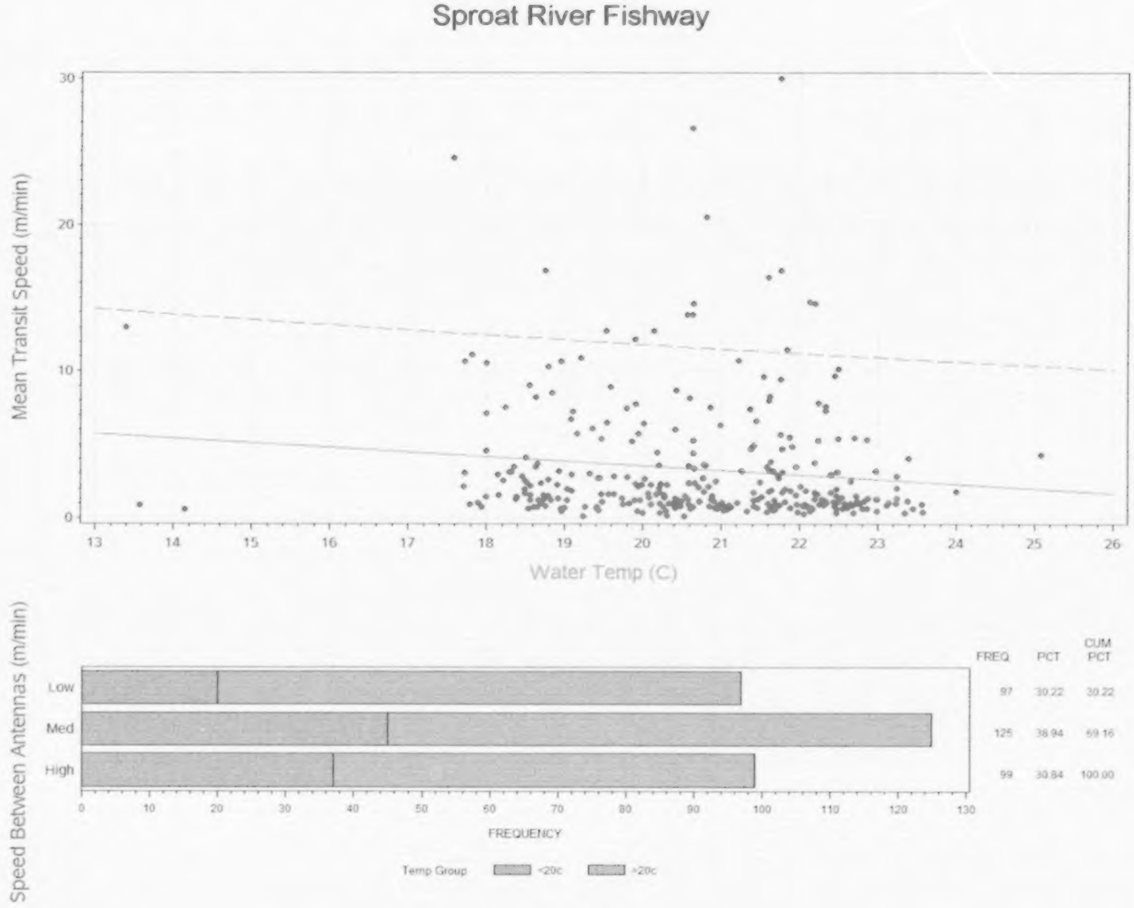

Sproat River Fishway

Figure 43. Mean transit speed (meters per minute) for PIT-tagged Sockeye between antennas 1 and 2 in the Sproat fishway, as a function of concurrent hourly mean water temperature (parametric linear regression (top): $Y = 9.7 - 0.31 * X$; $r^2 = 0.03$; $P = .001$; $n = 321$; and non-parametric frequency analysis at 20°C threshold ($P < 0.05$, $n = 321$).

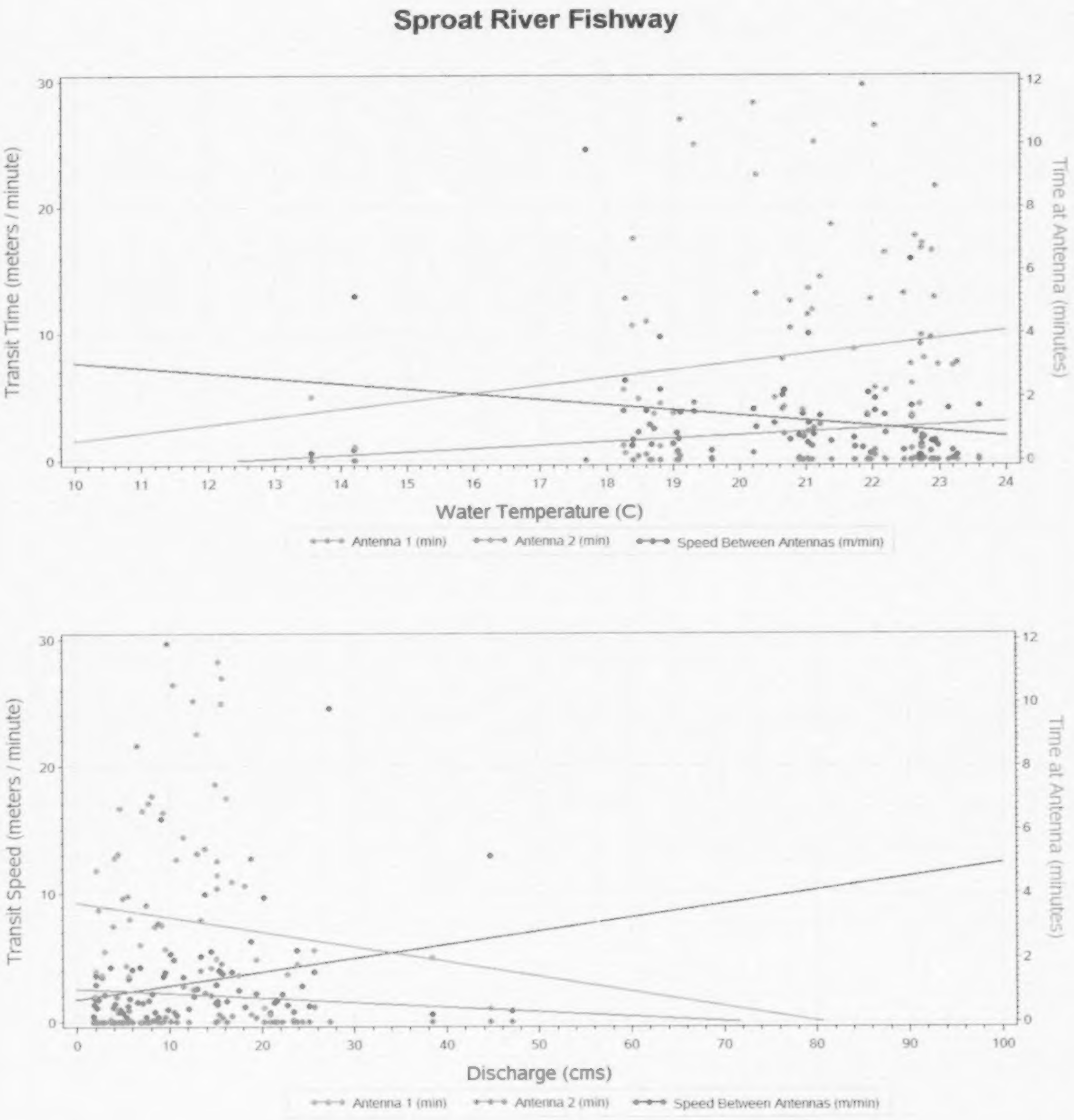
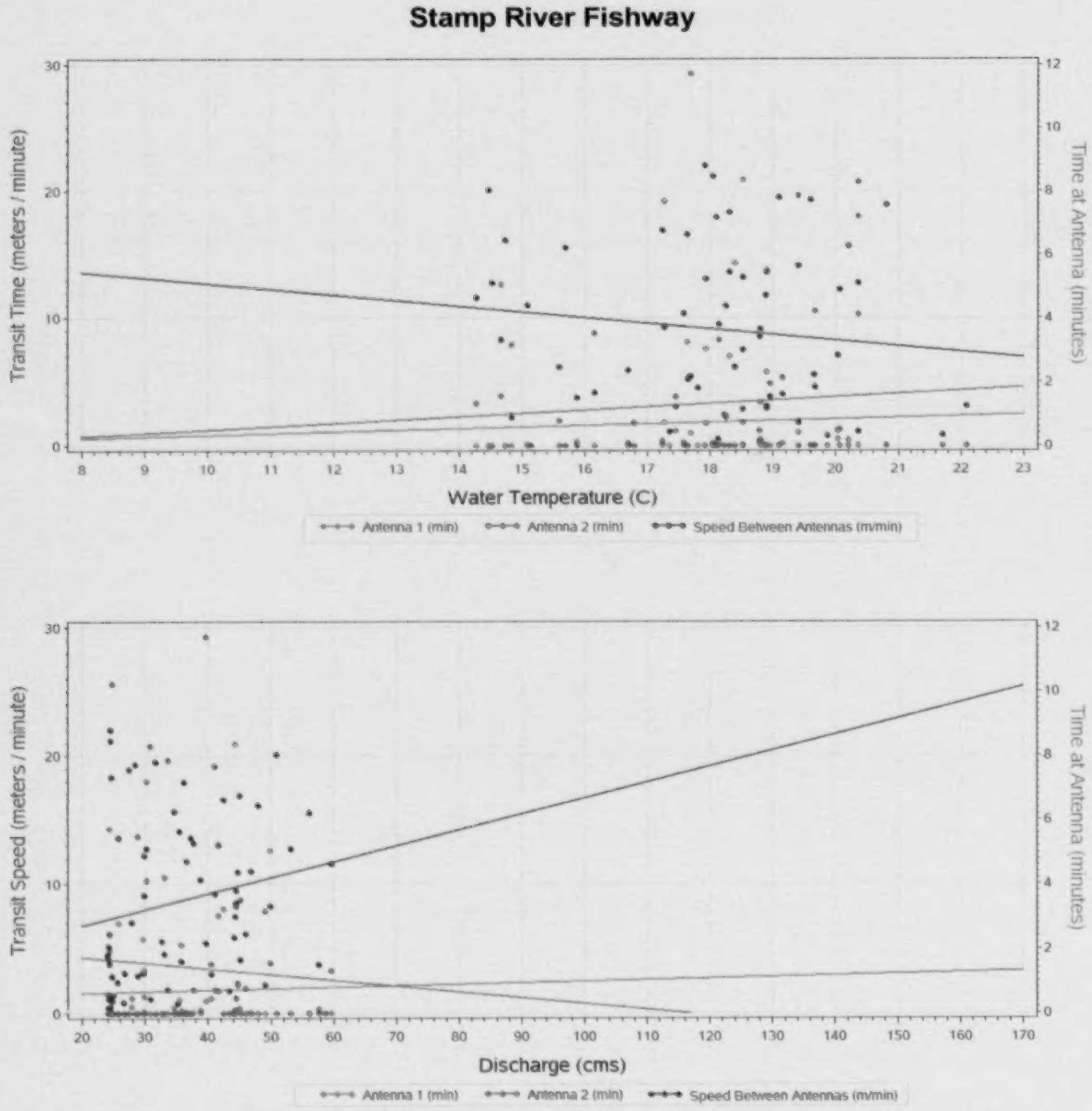
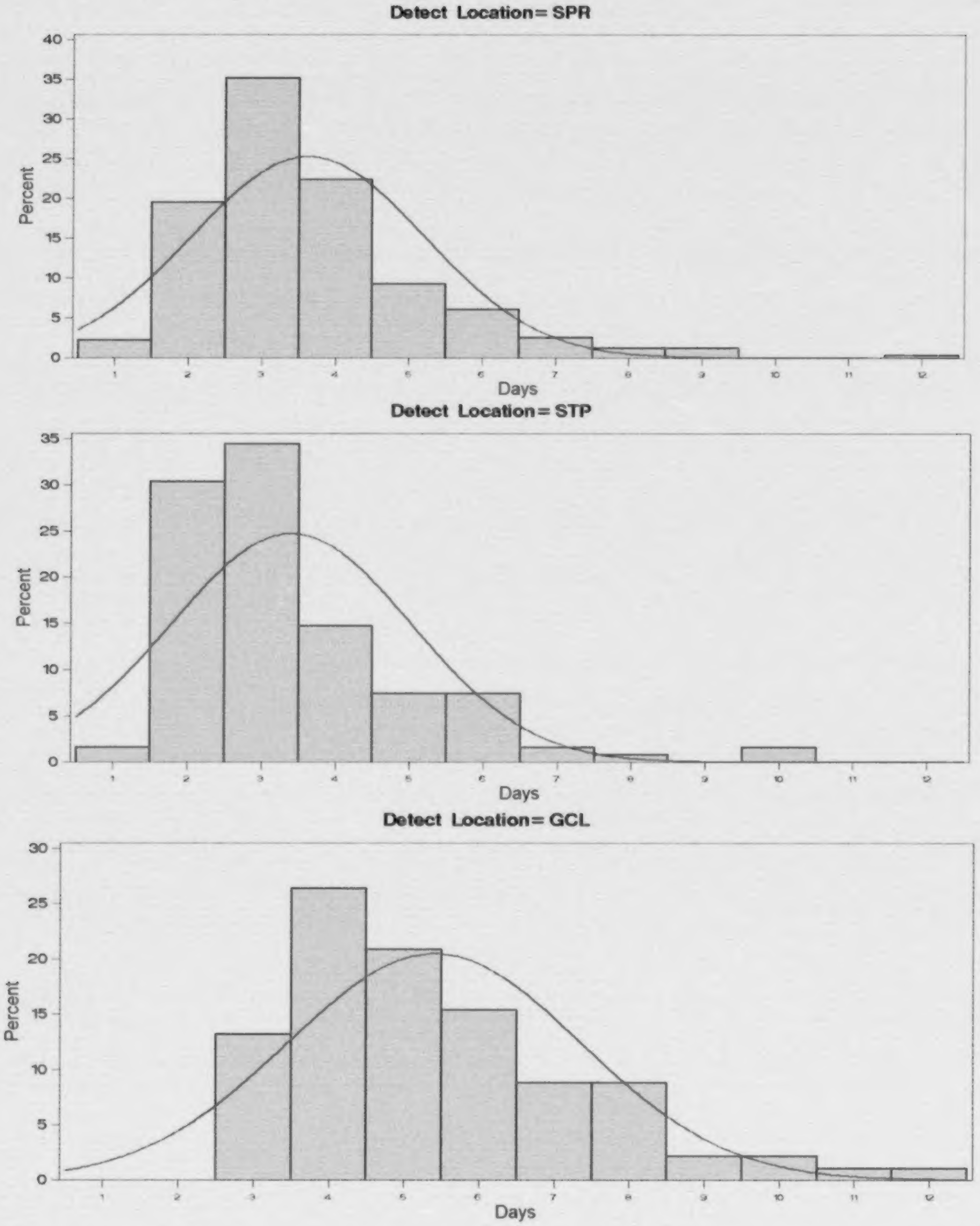


Figure 44. Daily mean tag transit speed (meters per minute) between Sproat fishway antennas (blue), duration at Sproat antenna 1 (red), and Sproat antenna 2 (green), as a function of daily mean Sproat River water temperature (top) and discharge (bottom).



Stamp River Fishway

Figure 45. Daily mean tag transit speed (meters per minute) between Stamp fishway antennas (blue), duration at Stamp antenna 1 (red), and Stamp antenna 2 (green), as a function of Stamp River daily mean water temperature (top) and discharge (bottom).


Detect Location= SPR

Detect Location= STP

Detect Location= GCL

Figure 46. Travel time (days) for fish tagged at Papermill Dam by tag detection location (Sproat, N=313, top; Stamp, N=122, middle; GCL, N=91, bottom). Outliers of 13 days or more excluded.

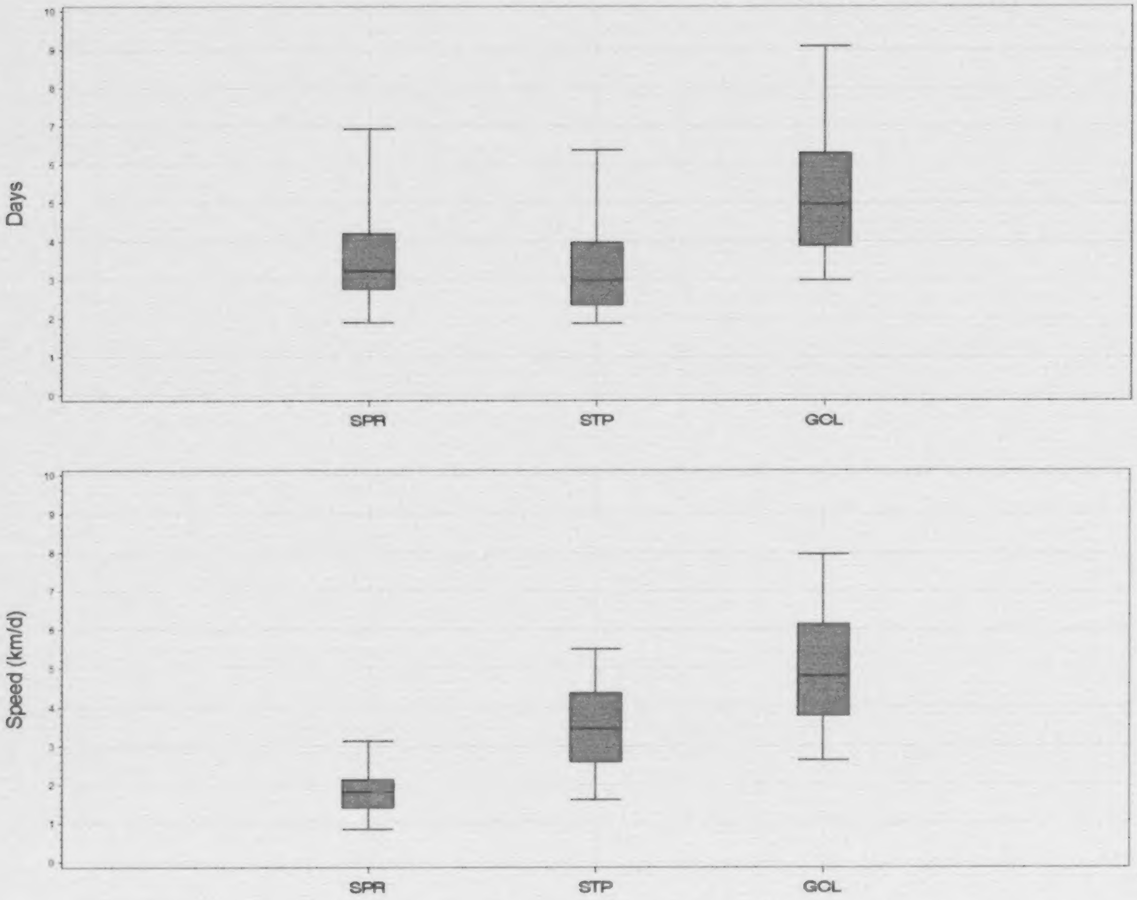
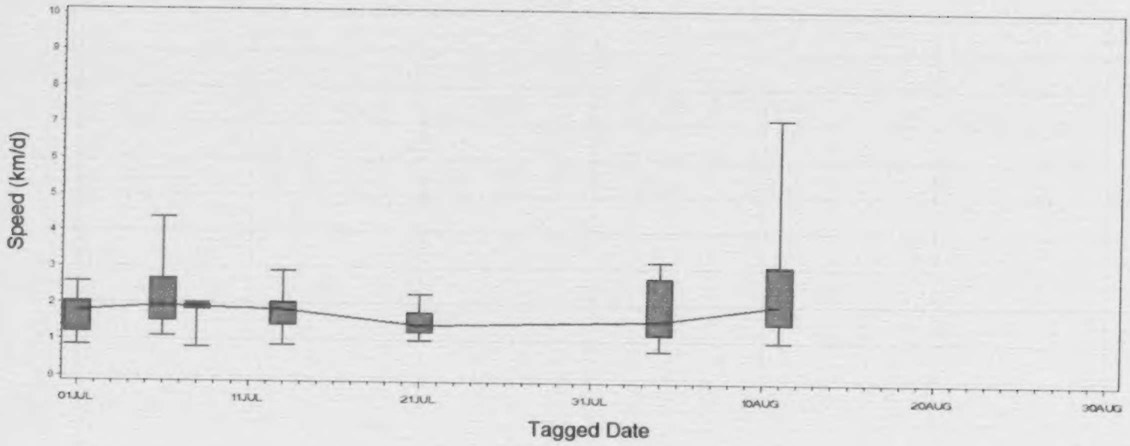


Figure 47. Median (horizontal line) and quartile box plots of travel time (days, top) and travel speed (km/d, bottom) for fish tagged at Papermill Dam detected at Sproat (N=313), Stamp (N=122), and GCL (N=91) fishways. Outliers of 13 days or more excluded.

Location= SPR



Location= STP

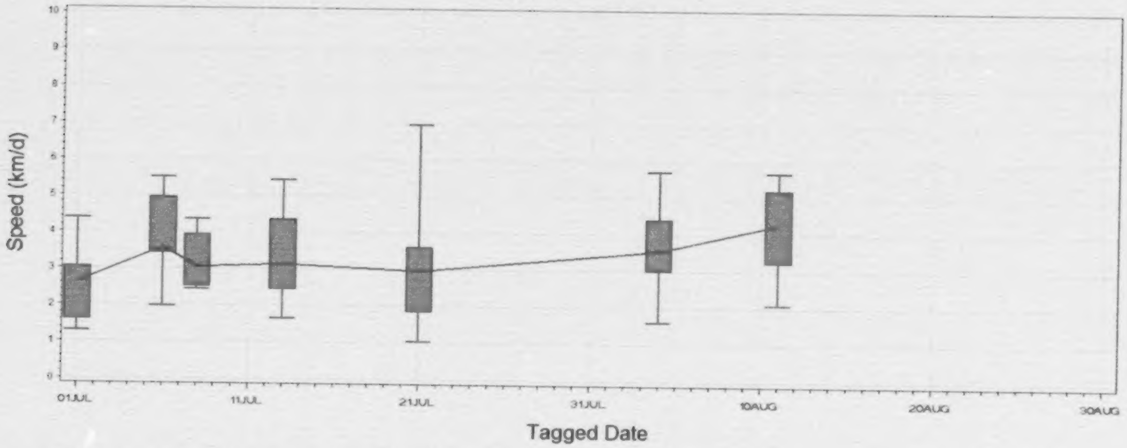


Figure 48. Median (horizontal line) and quartile box plots of travel time (days, top) and travel speed (km/d, bottom) by tag date for fish tagged at Papermill Dam, detected at Sproat (top), and Stamp (bottom) fishways.

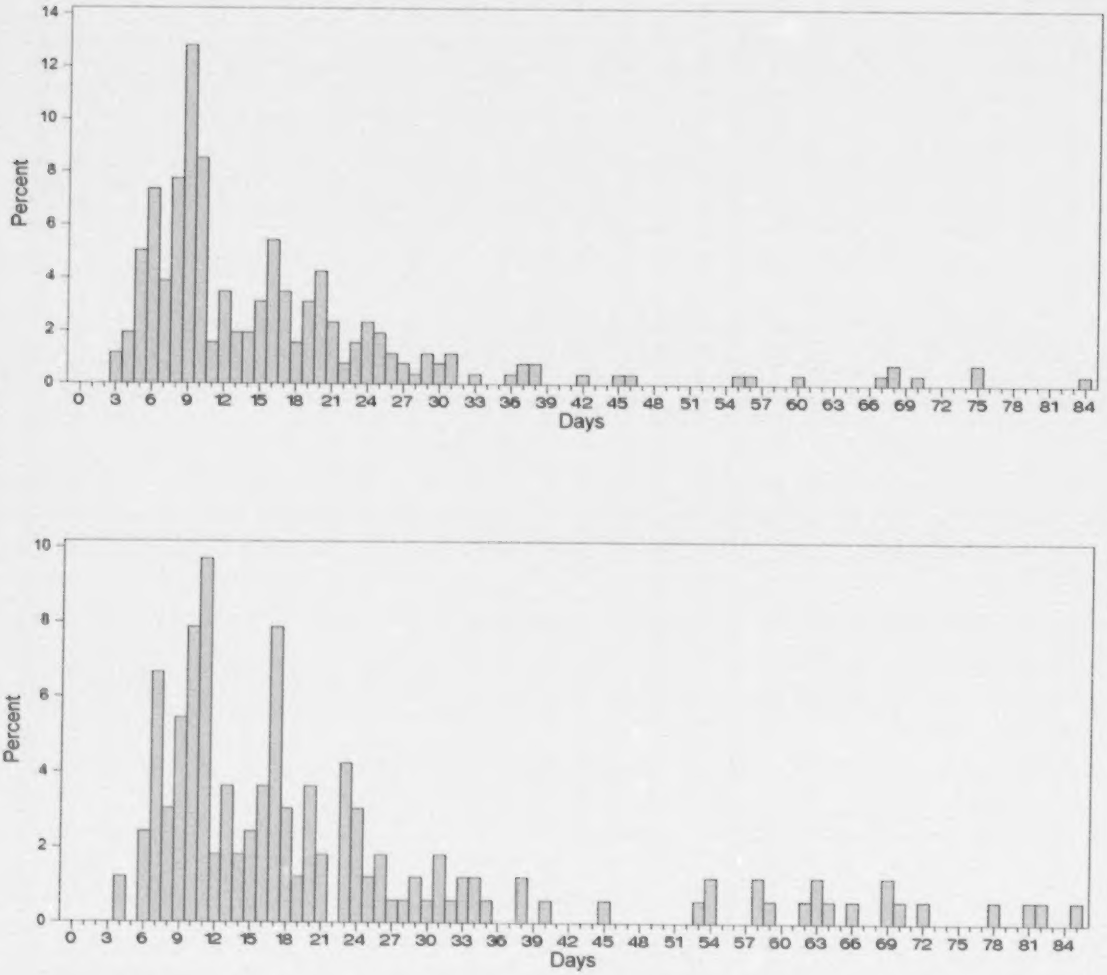


Figure 49. Frequency distribution of travel time (days) for fish tagged in Alberni Inlet, detected at Sproat (top), and Stamp (bottom) fishways.

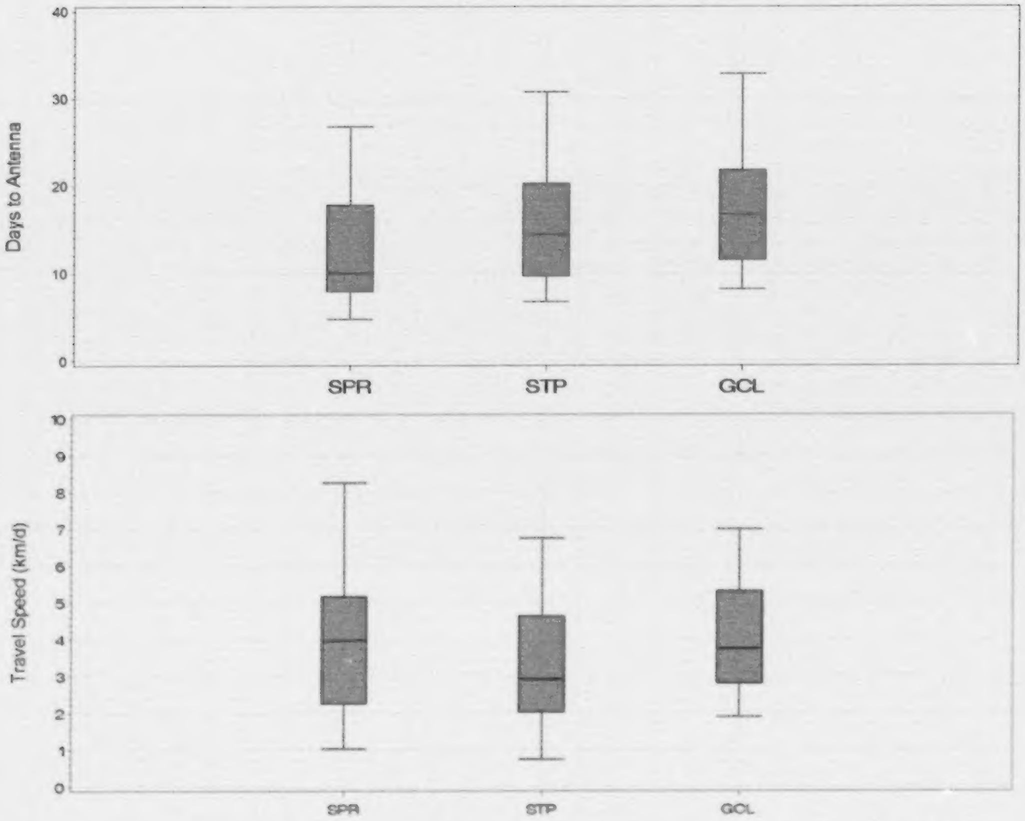


Figure 50. Median (horizontal line) and quartile box plots of travel time (days, top) and travel speed (km/d, bottom) by tag date for fish tagged in Alberni Inlet, detected at Sproat (top), and Stamp (bottom) fishways.

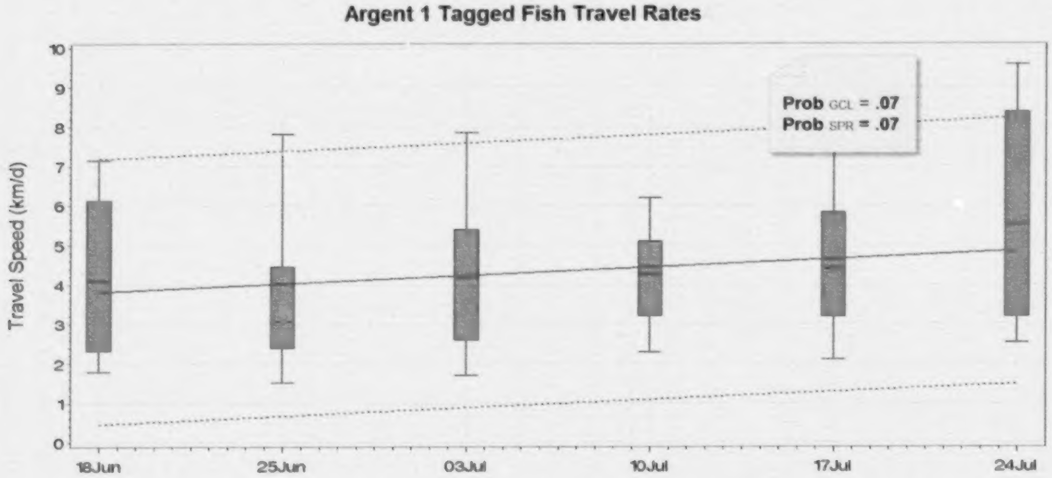

Argent 1 Tagged Fish Travel Rates

Figure 51. Median (horizontal line) and quartile box plots of travel time (days, top) and travel speed (km/d, bottom) by tag date for fish tagged in Alberni Inlet, detected at Sproat (top), and Stamp (bottom) fishways.

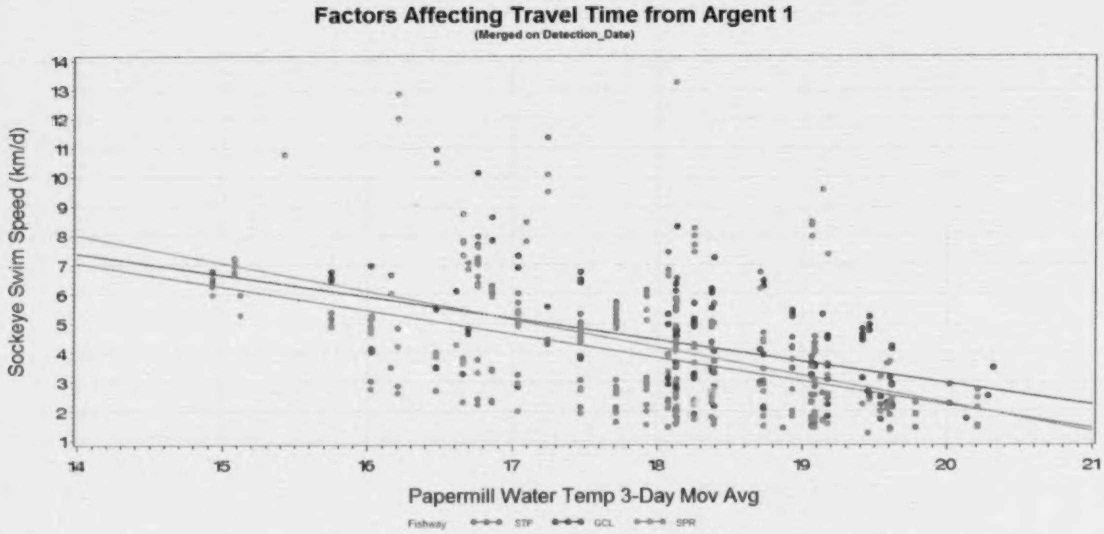


Figure 52. Mean Sockeye travel rate (km/d) as a function of Somass River 3-day moving average water temperature (°C, at Papermill Dam) for individual tags detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

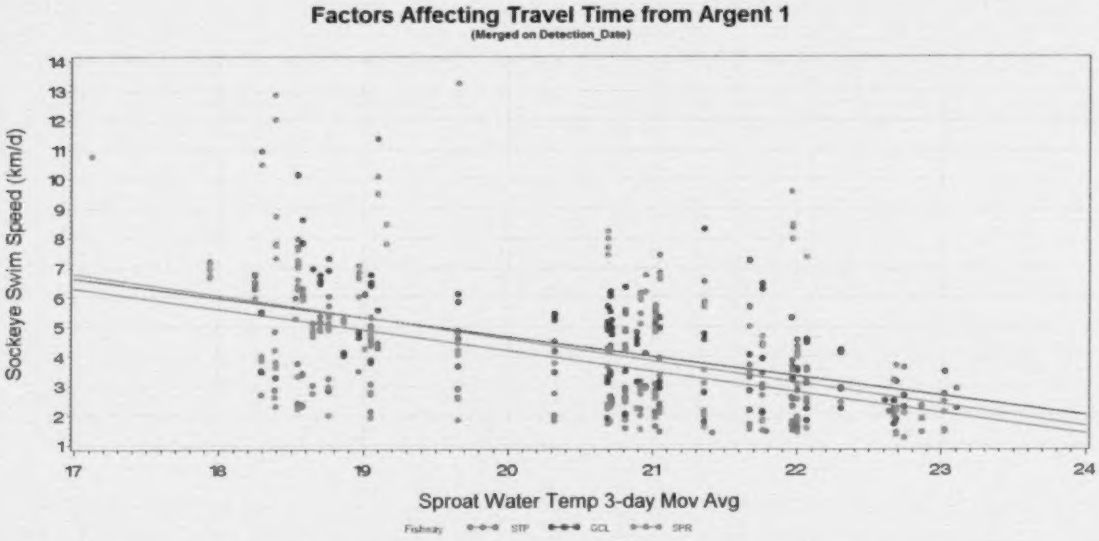


Figure 53. Mean Sockeye travel rate (km/d) as a function of Sproat River 3-day moving average water temperature (°C) for individual tags detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

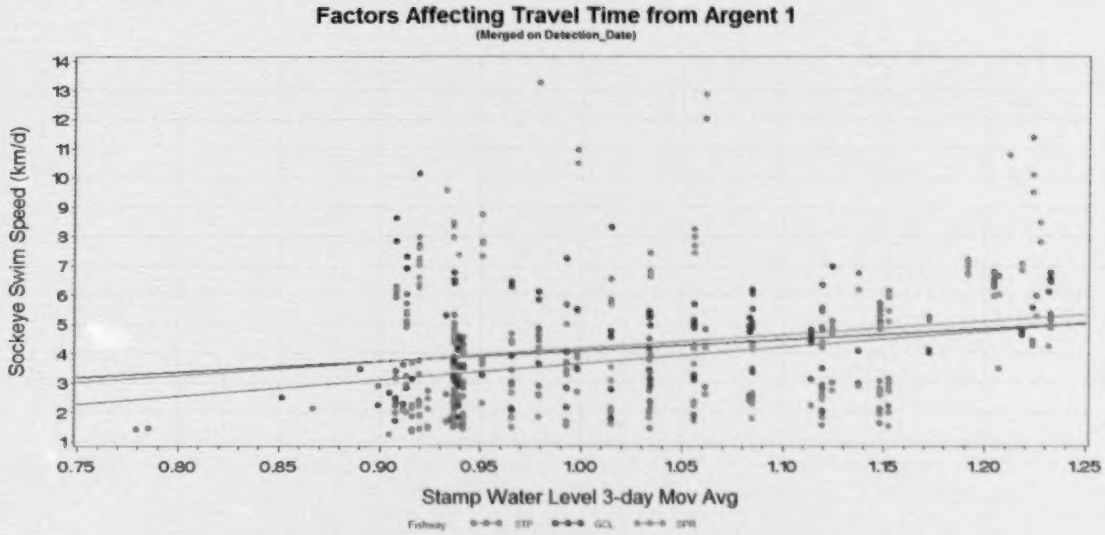


Figure 54. Mean Sockeye travel rate (km/d) as a function of Stamp River 3-day moving average water level (m) for individual tags detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

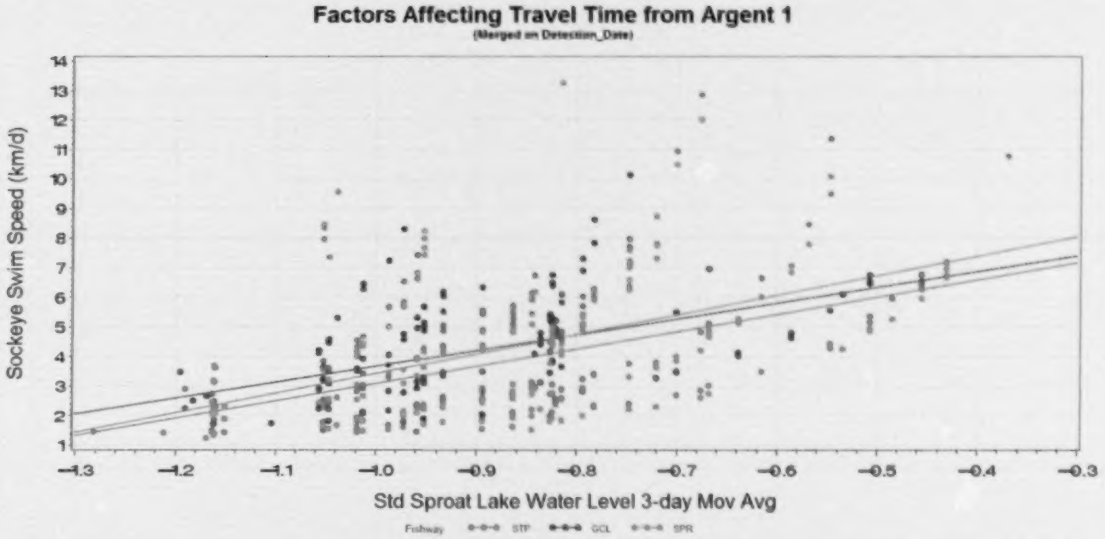


Figure 55. Mean Sockeye travel rate (km/d) as a function of Sproat Lake 3-day moving average water level (standardized: $\mu=0$; $\sigma=1$) for individual tags detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

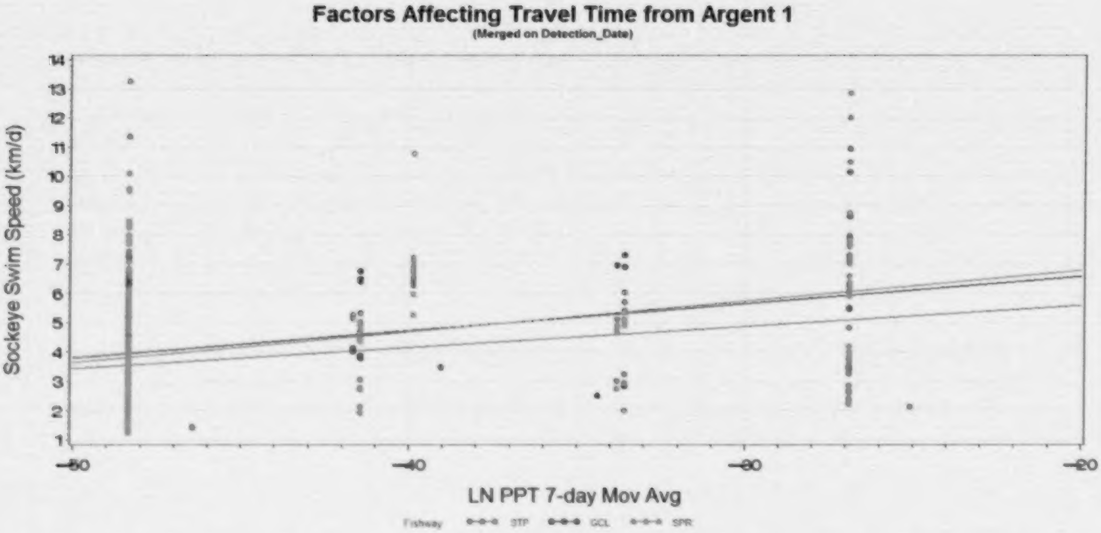


Figure 56. Mean Sockeye travel rate (km/d) as a function of 7-day moving total precipitation (log-transformed) for individual tags detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

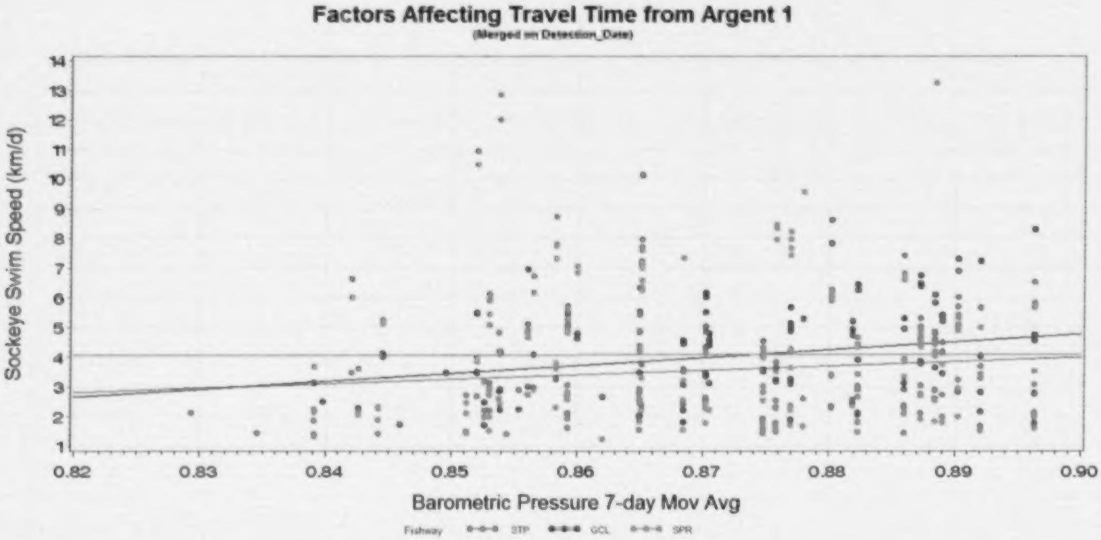


Figure 57. Mean Sockeye travel rate (km/d) as a function of 7-day moving average barometric pressure (mm) for individual tags detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

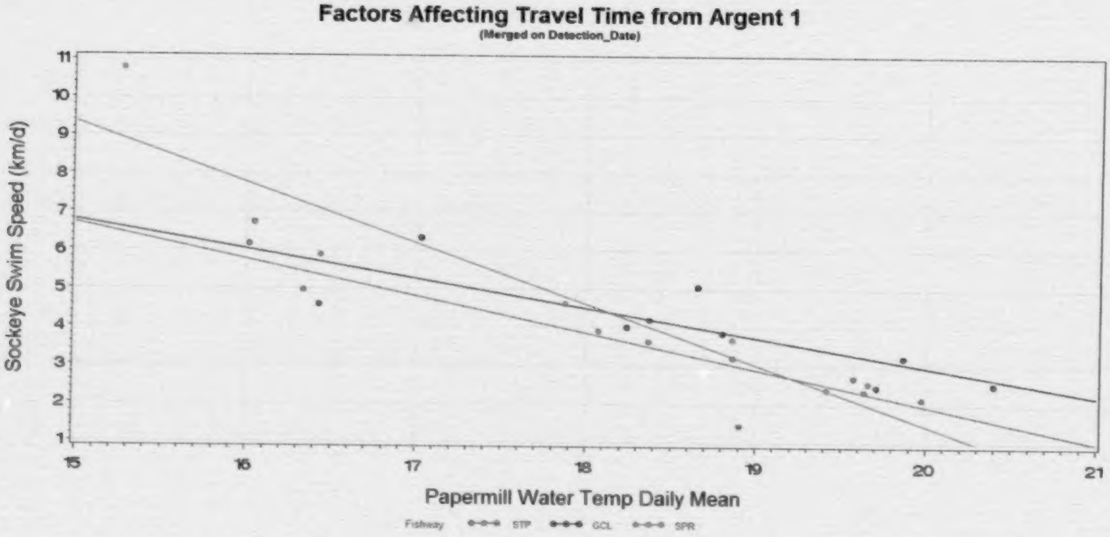


Figure 58. Weekly mean Sockeye travel rate (km/d) as a function of weekly mean of Somass River 3-day moving average water temperature (°C, at Papermill Dam) for individual tags detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

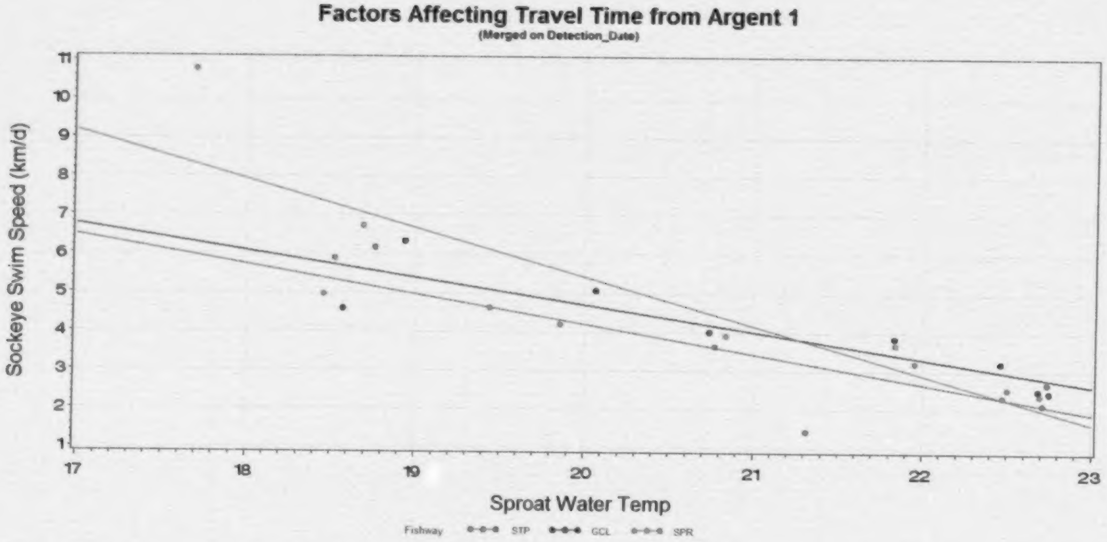


Figure 59. Weekly mean Sockeye travel rate (km/d) as a function of weekly mean of Sproat River 3-day moving average water temperature (°C) for individual tags detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

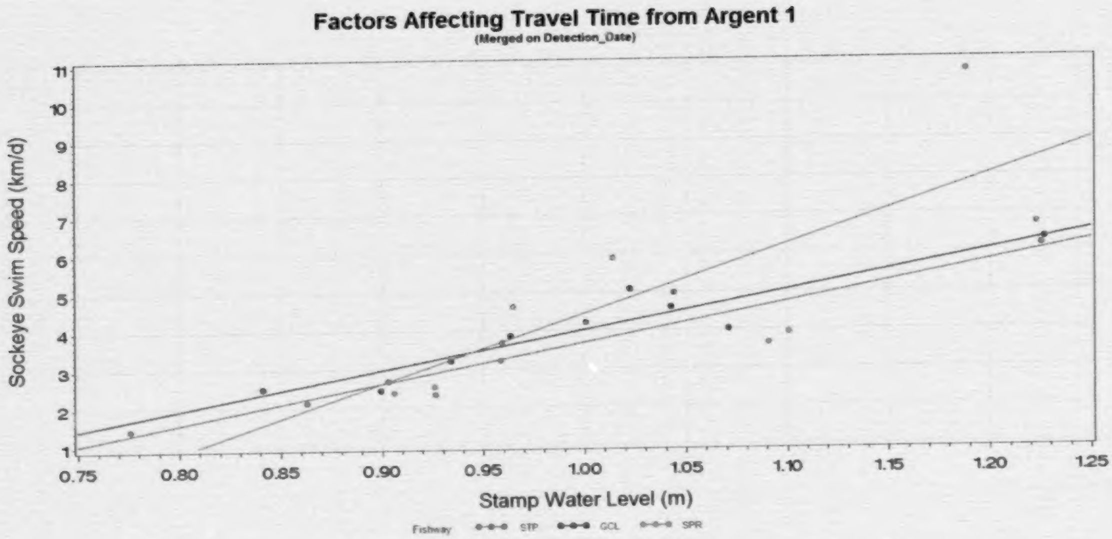


Figure 60. Weekly mean Sockeye travel rate (km/d) as a function of weekly mean of Stamp River 3-day moving average water level (m) for individual tags detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

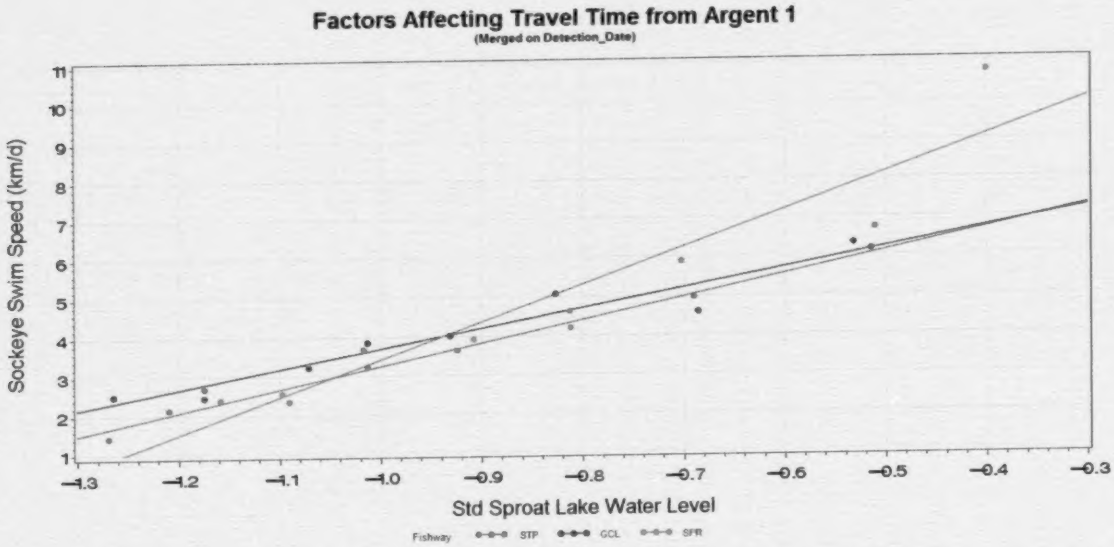


Figure 61. Weekly mean Sockeye travel rate (km/d) as a function of weekly mean of Sproat Lake 3-day moving average water level (standardized: μ=0; σ=1) for individual tags detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

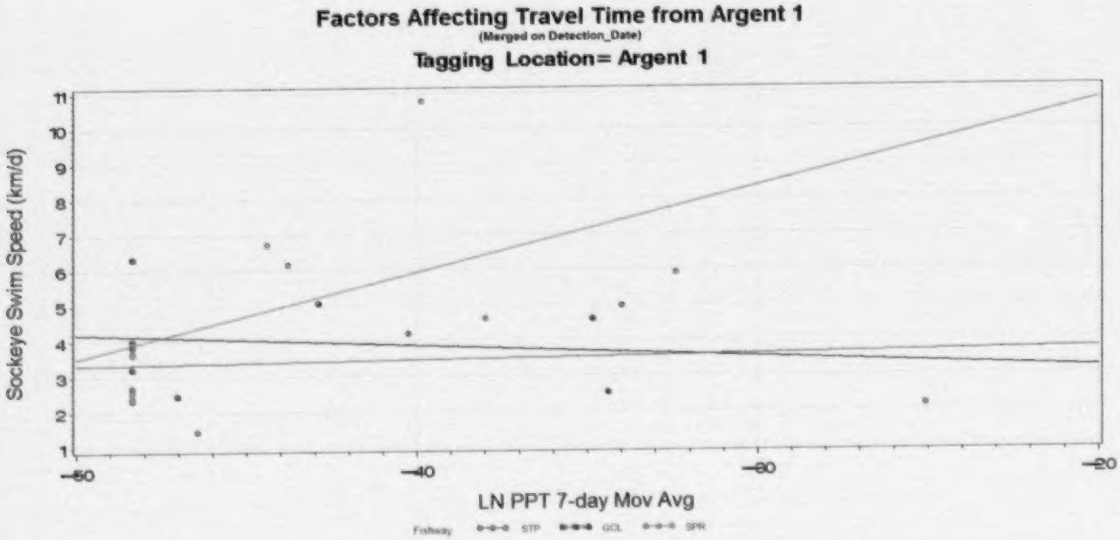


Figure 62. Weekly mean Sockeye travel rate (km/d) as a function of weekly mean of 7-day moving total precipitation (log-transformed) for individual tags detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

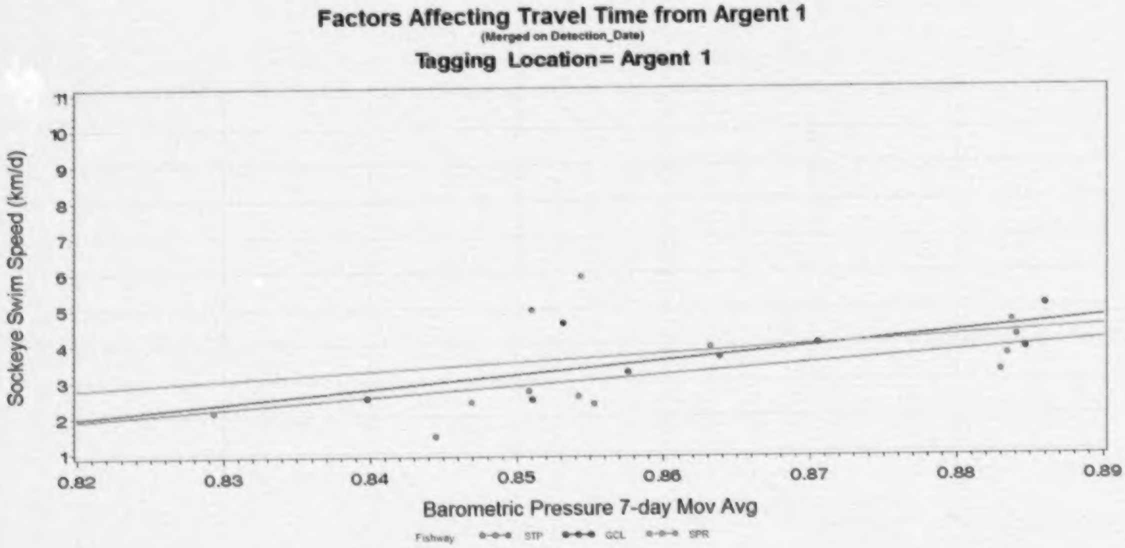


Figure 63. Weekly mean Sockeye travel rate (km/d) as a function of weekly mean of 7-day moving average barometric pressure (mm) for individual tags detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

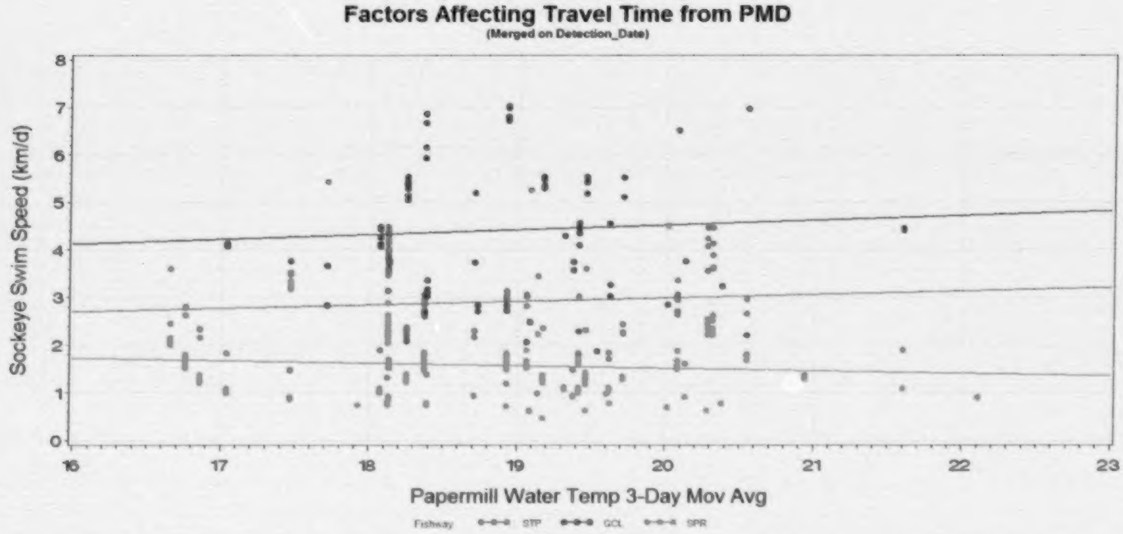


Figure 64. Mean Sockeye travel rate (km/d) as a function of Somass River 3-day moving average water temperature (°C, at Papermill Dam) for individual tags released at Papermill Dam and detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

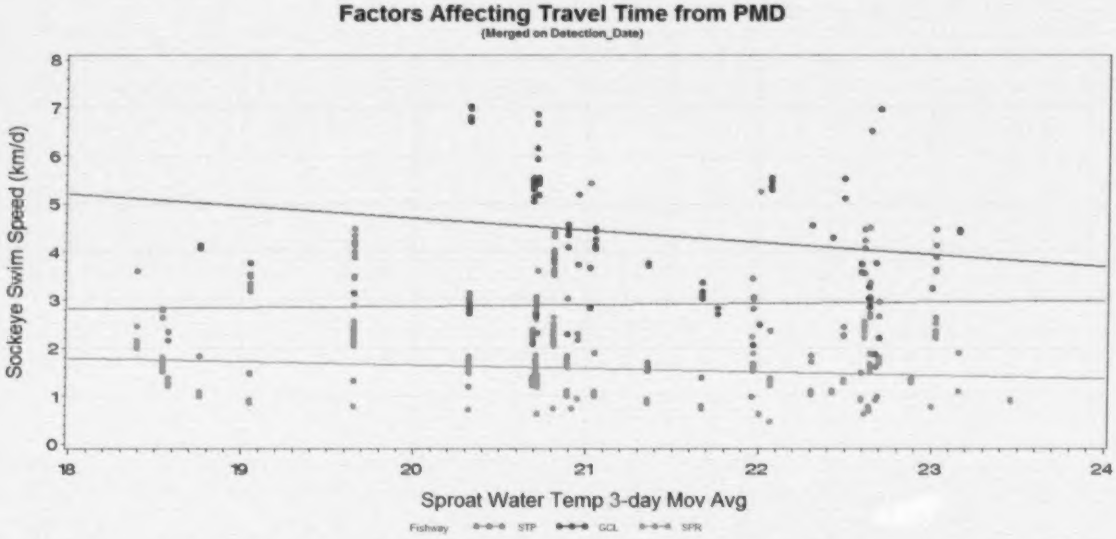


Figure 65. Mean Sockeye travel rate (km/d) as a function of Sproat River 3-day moving average water temperature (°C) for individual tags released at Papermill Dam and detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

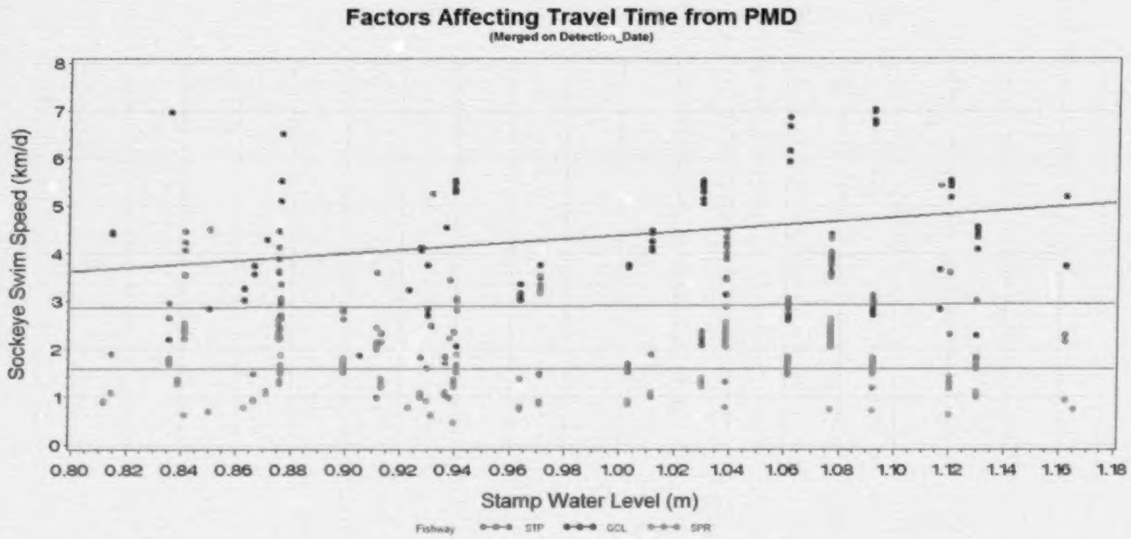


Figure 66. Mean Sockeye travel rate (km/d) as a function of Stamp River water level (m) for individual tags released at Papermill Dam and detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

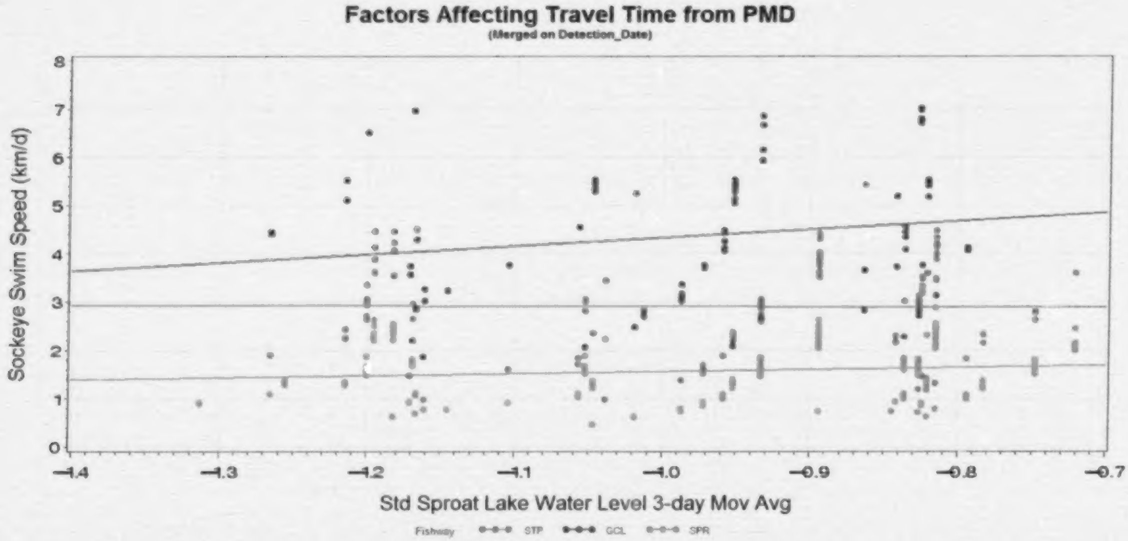


Figure 67. Mean Sockeye travel rate (km/d) as a function of Sproat Lake 3-day moving average water level (standardized: μ=0; σ=1) for individual tags released at Papermill Dam and detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

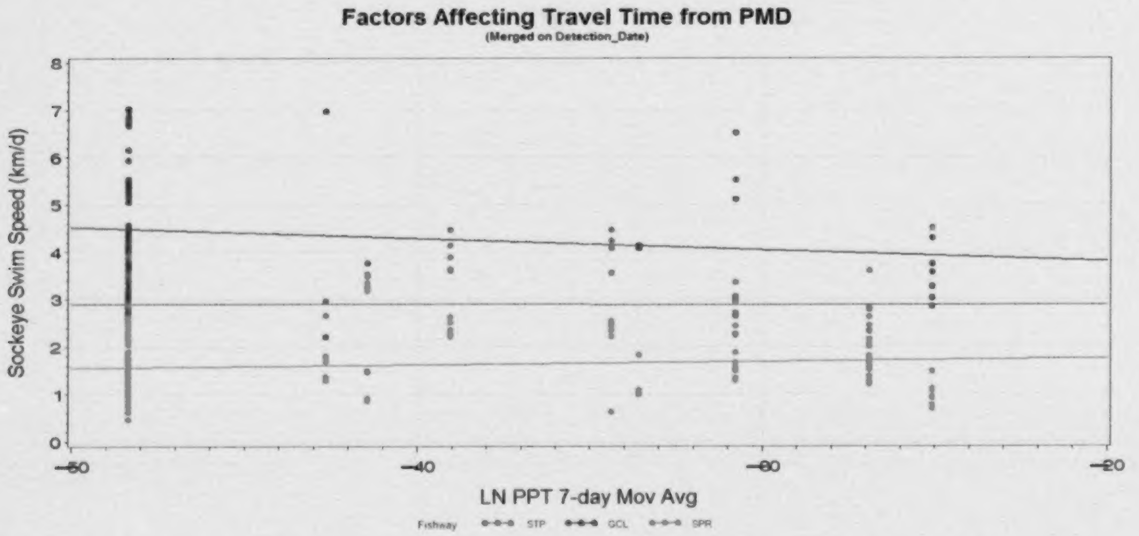


Figure 68. Mean Sockeye travel rate (km/d) as a function of 7-day moving total precipitation (log transformed) for individual tags released at Papermill Dam and detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

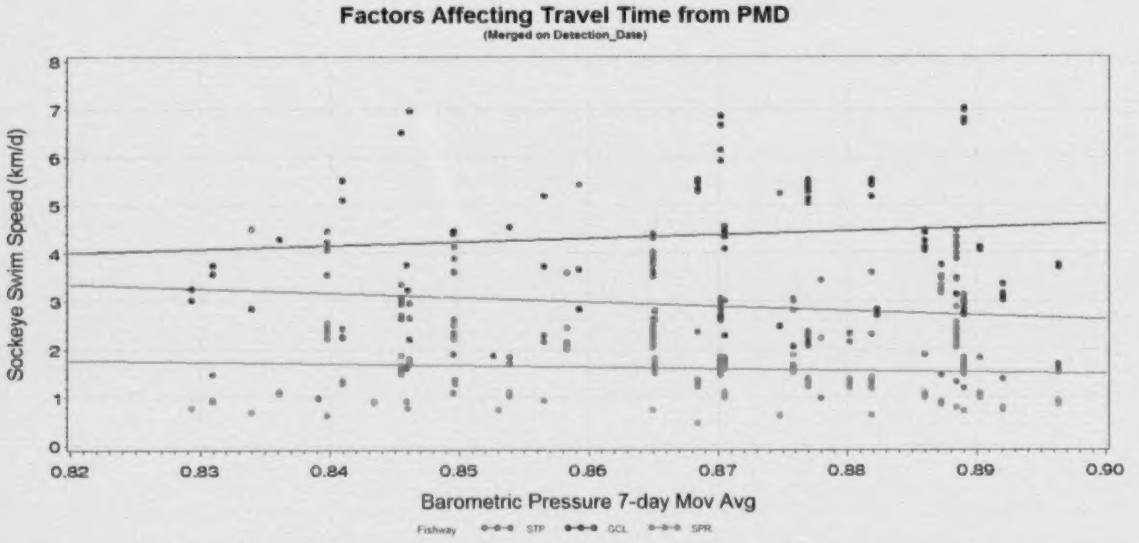


Figure 69. Mean Sockeye travel rate (km/d) as a function of 7-day moving average barometric pressure (mm) for individual tags released at Papermill Dam and detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

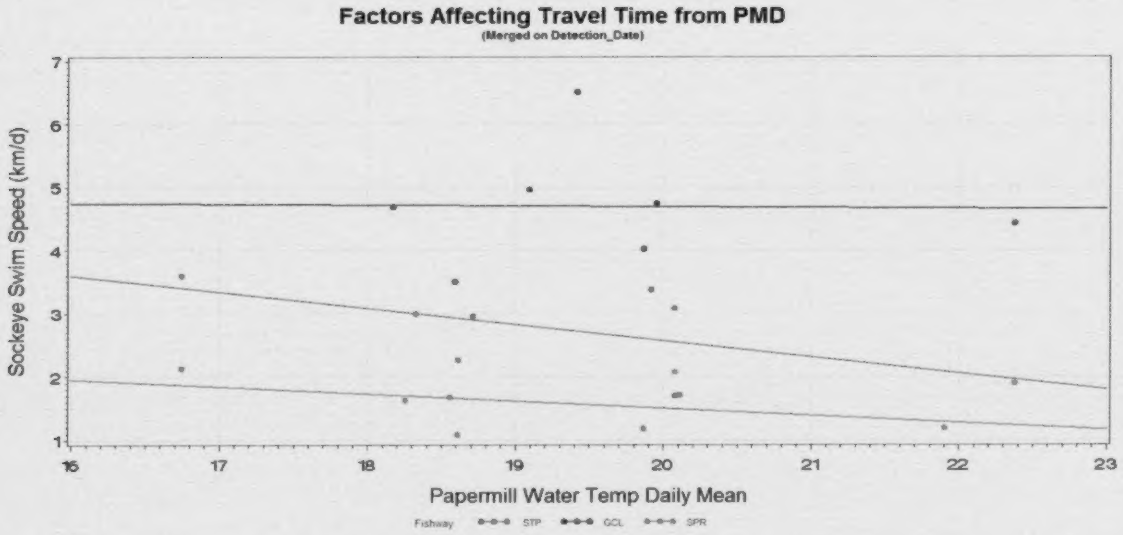


Figure 70. Weekly mean Sockeye travel rate (km/d) as a function of weekly mean of Somass River water temperature (°C, at Papermill Dam) for tags released at Papermill Dam and detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

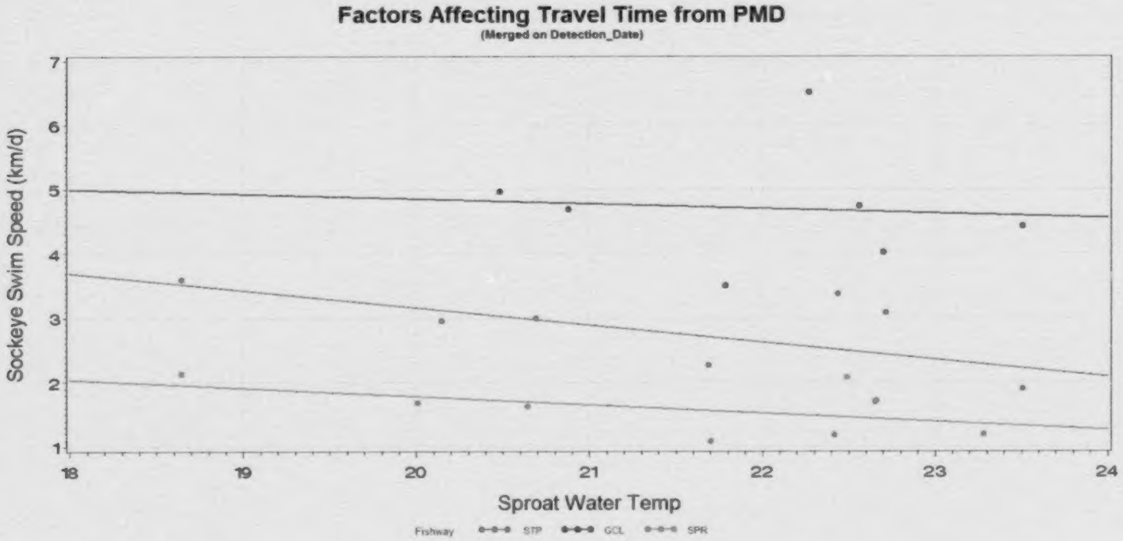


Figure 71. Weekly mean Sockeye travel rate (km/d) as a function of weekly mean of Sproat River water temperature (°C) for tags released at Papermill Dam and detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

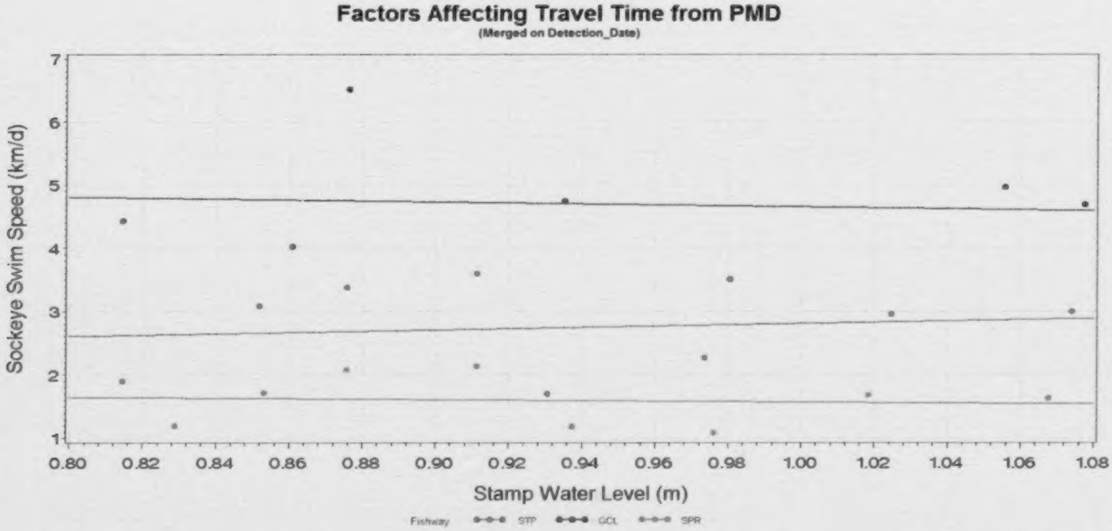


Figure 72. Weekly mean Sockeye travel rate (km/d) as a function of weekly mean of Stamp River water level (m) for tags released at Papermill Dam and detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

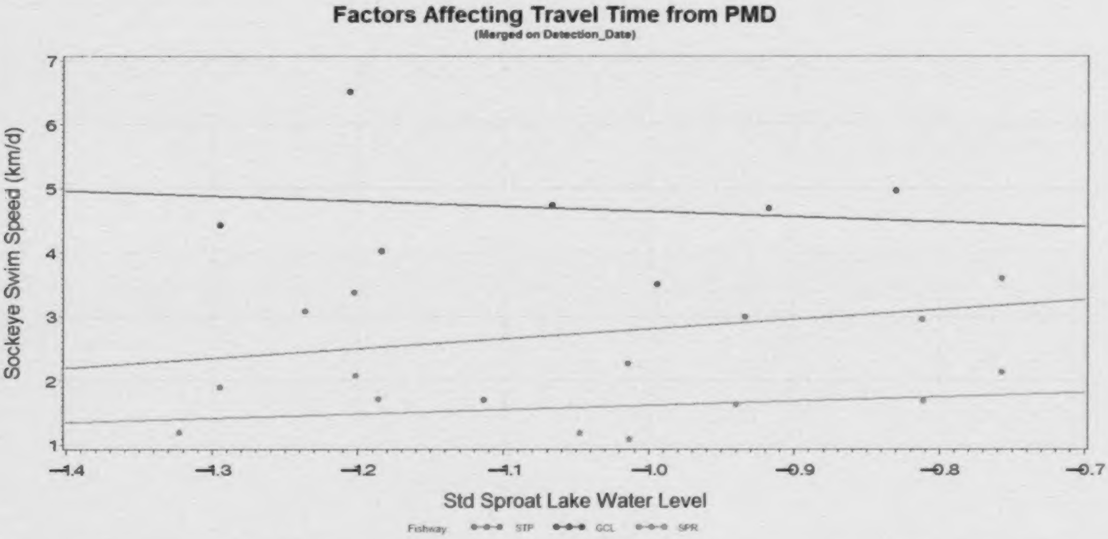


Figure 73. Weekly mean Sockeye travel rate (km/d) as a function of weekly mean of Sproat Lake water level (standardized: μ=0; σ=1) for tags released at Papermill Dam and detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

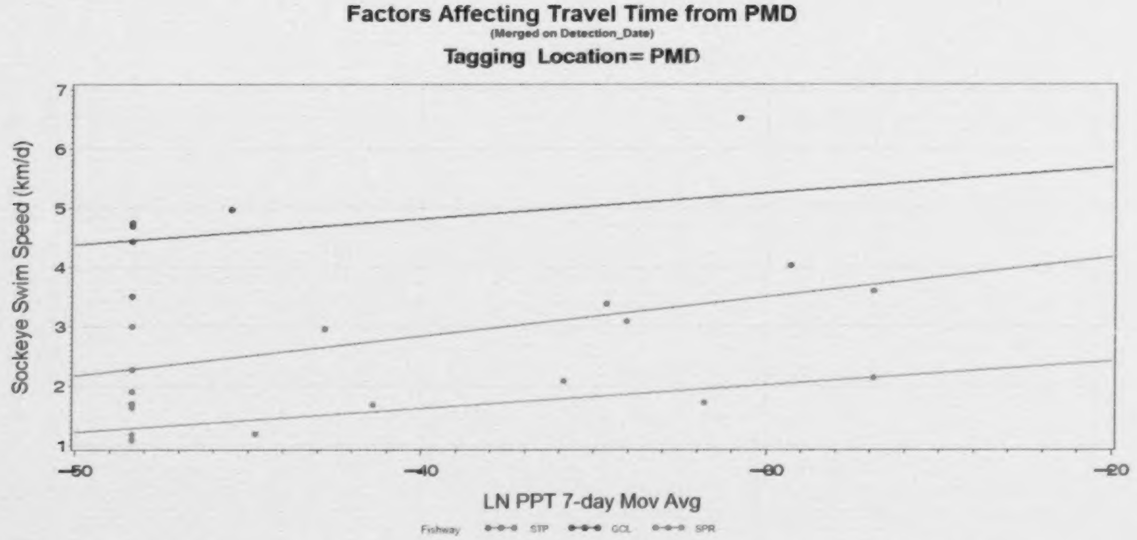

Factors Affecting Travel Time from PMD
(Merged on Detection_Date)
Tagging Location= PMD

Figure 74. Weekly mean Sockeye travel rate (km/d) as a function of weekly mean of 7-day moving total precipitation (log-transformed) for tags released at Papermill Dam and detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

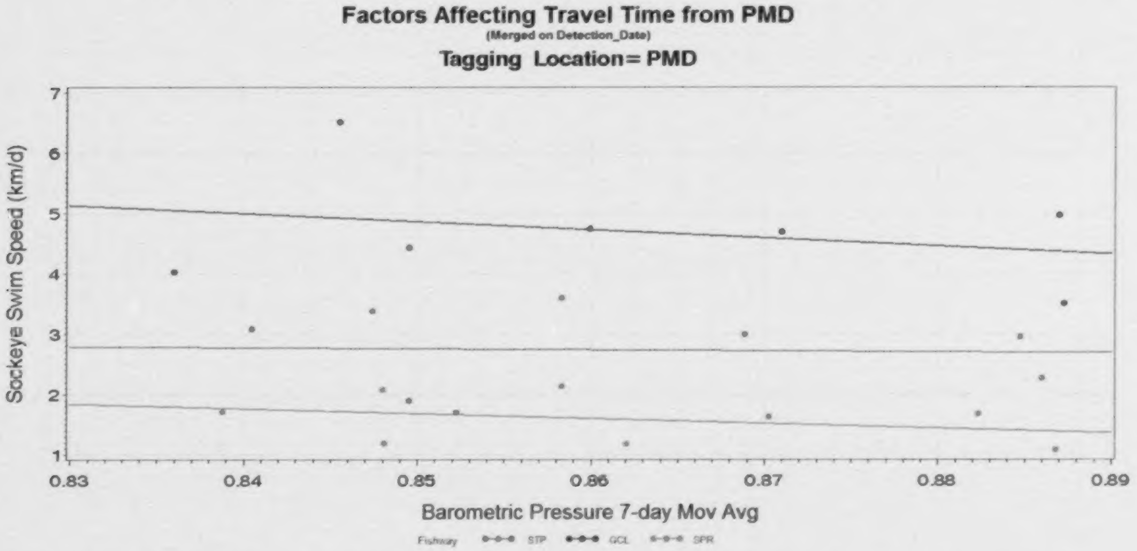

Factors Affecting Travel Time from PMD
(Merged on Detection_Date)
Tagging Location= PMD

Figure 75. Weekly mean Sockeye travel rate (km/d) as a function of weekly mean of 7-day moving average barometric pressure (mm) for tags released at Papermill Dam and detected at Stamp (green), Great Central (blue) and Sproat (red) fishways.

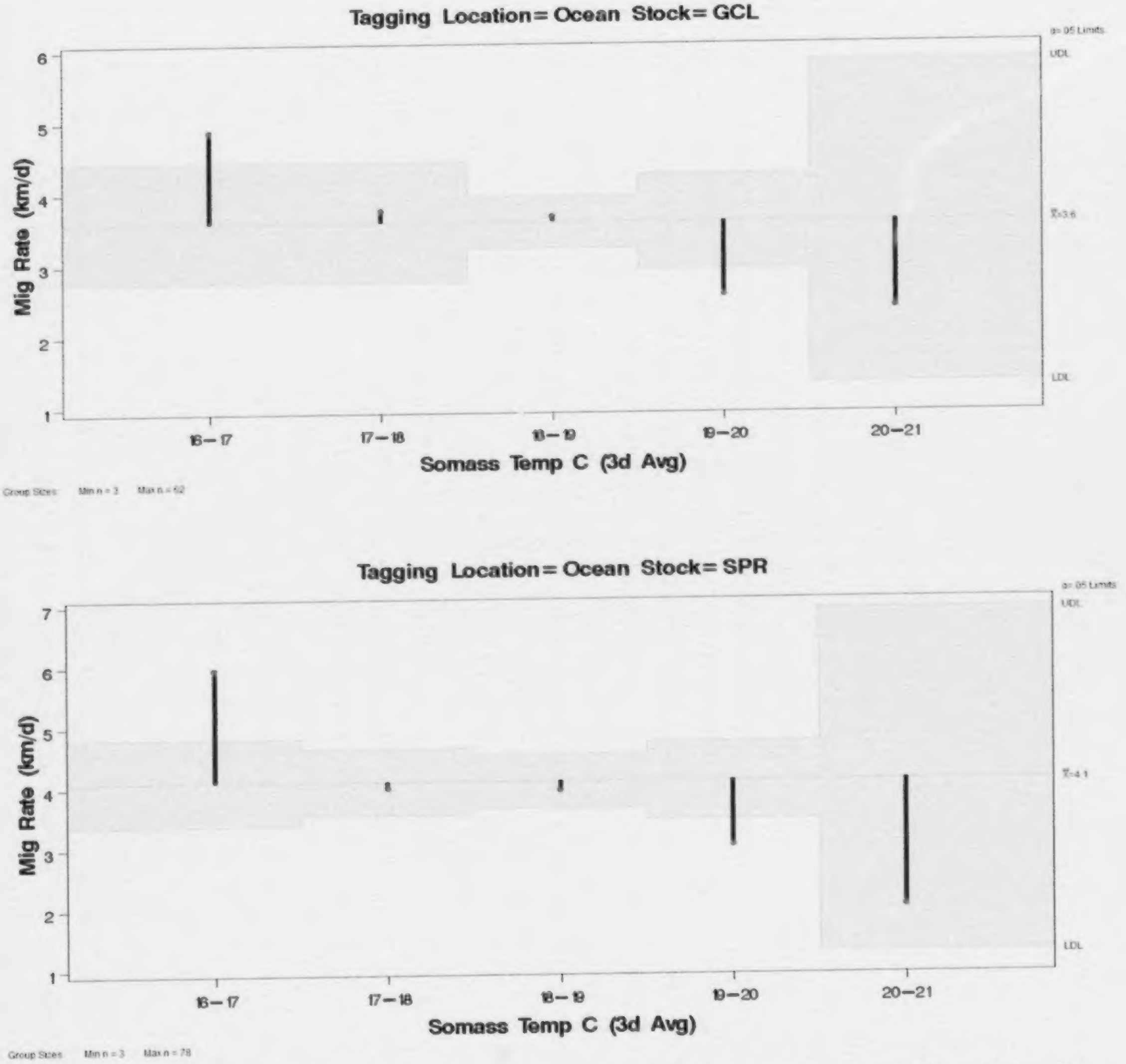


Figure 76. Needle plots of mean Sockeye migration rate (km/d) by category of 3-day moving average water temperature for ocean-tagged fish bound for Great Central (top) and Sproat (bottom) lakes. Shaded blue areas denote upper and lower decision limits for the null hypothesis that the category mean is not significantly different from the overall average (horizontal line).

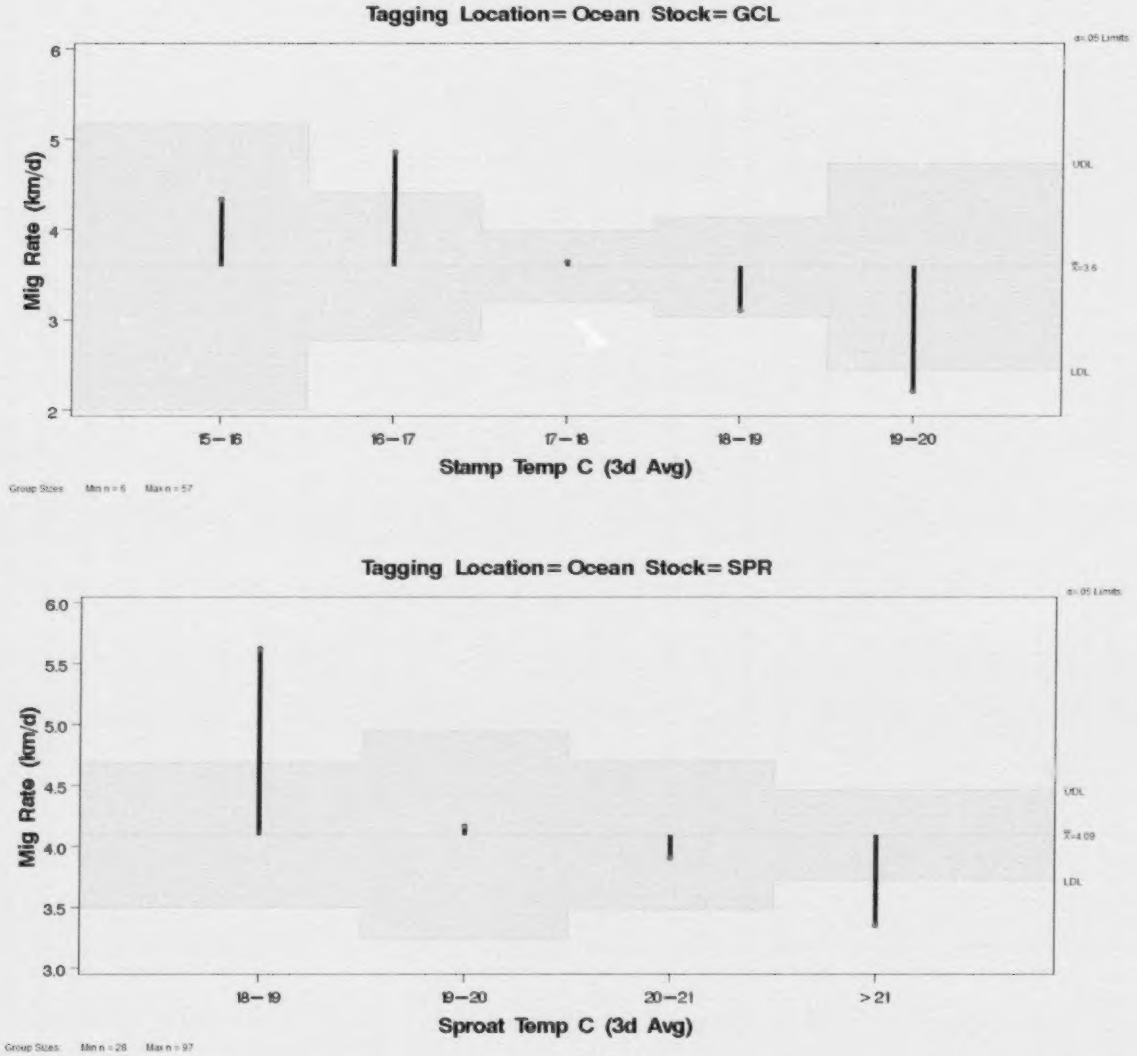


Figure 77. Needle plots of mean Sockeye migration rate (km/d) by category of 3-day moving average water temperature for ocean-tagged fish bound for Great Central Lake via the Stamp River (top), and for Sproat Lake via the Sproat River (bottom). Shaded blue areas denote upper and lower decision limits for the null hypothesis that the category mean is not significantly different from the overall average (horizontal line).

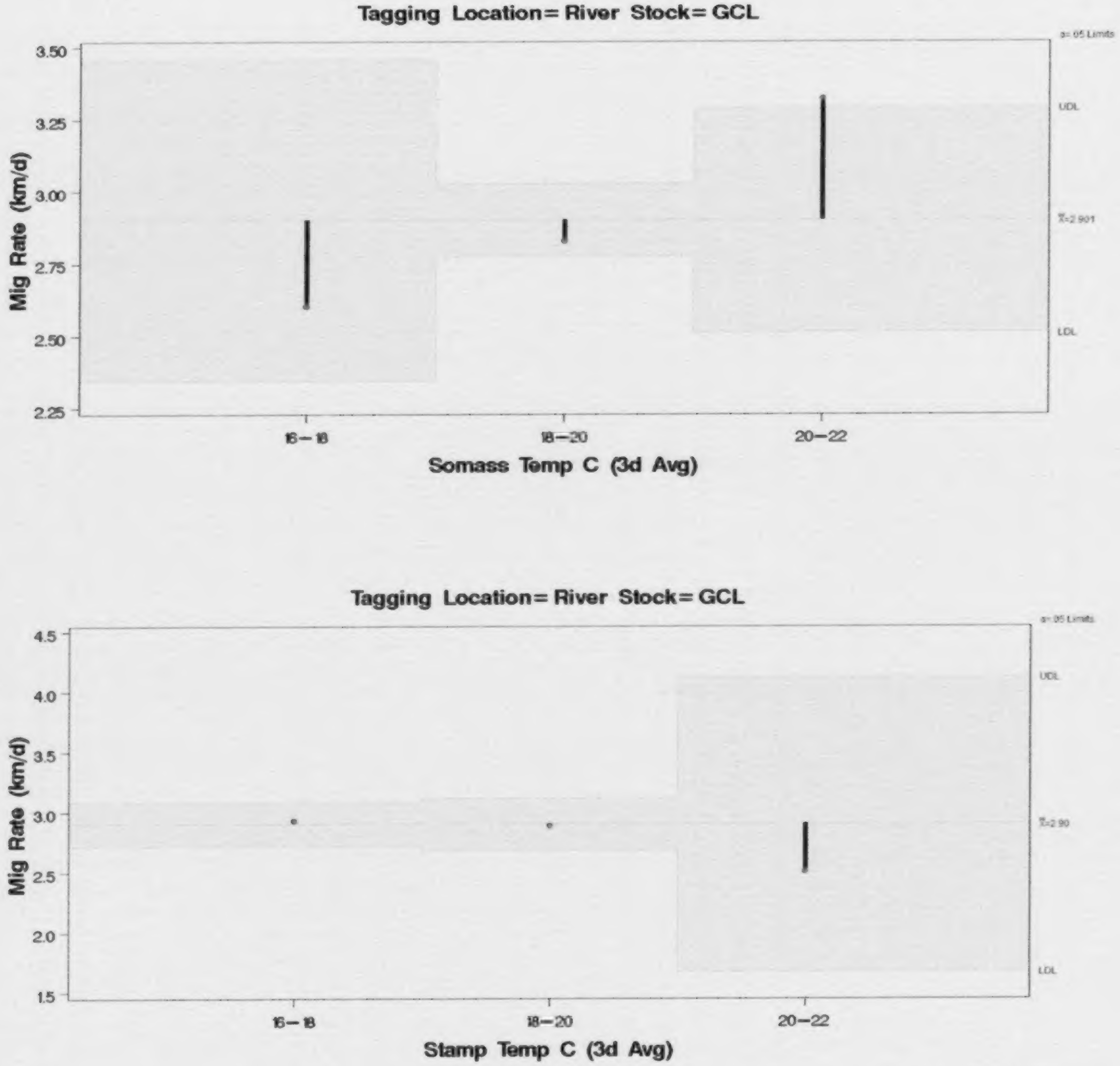


Figure 78. Needle plots of mean Sockeye migration rate (km/d) by category of 3-day moving average water temperature for river-tagged fish bound for Great Central Lake via the Somass River (top) and Stamp River (bottom). Shaded blue areas denote upper and lower decision limits for the null hypothesis that the category mean is not significantly different from the overall average (horizontal line).

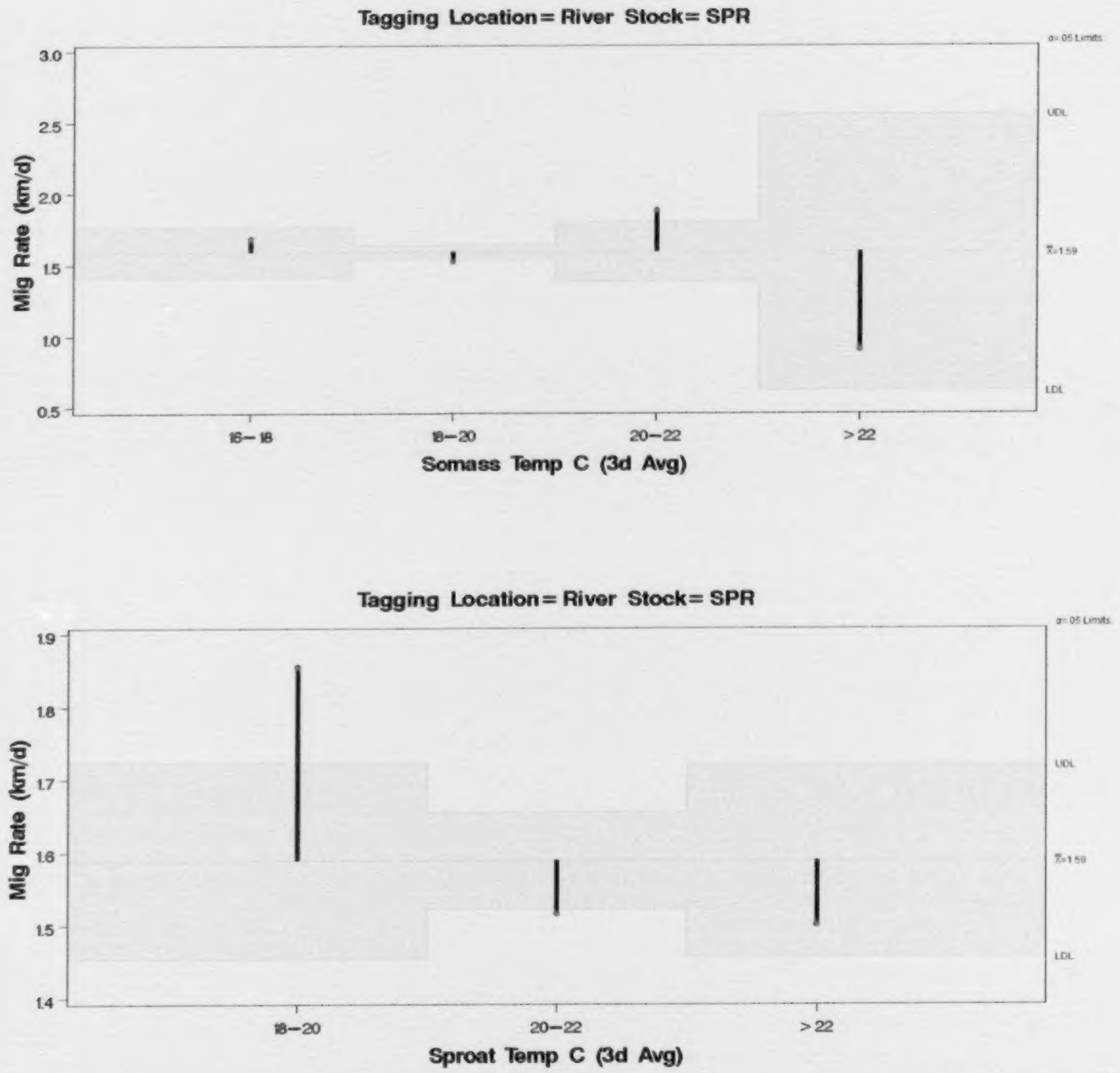


Figure 79. Needle plots of mean Sockeye migration rate (km/d) by category of 3-day moving average water temperature for river-tagged fish bound for Sproat Lake via the Somass River (top) and the Sproat River (bottom). Shaded blue areas denote upper and lower decision limits for the null hypothesis that the category mean is not significantly different from the overall average (horizontal line).

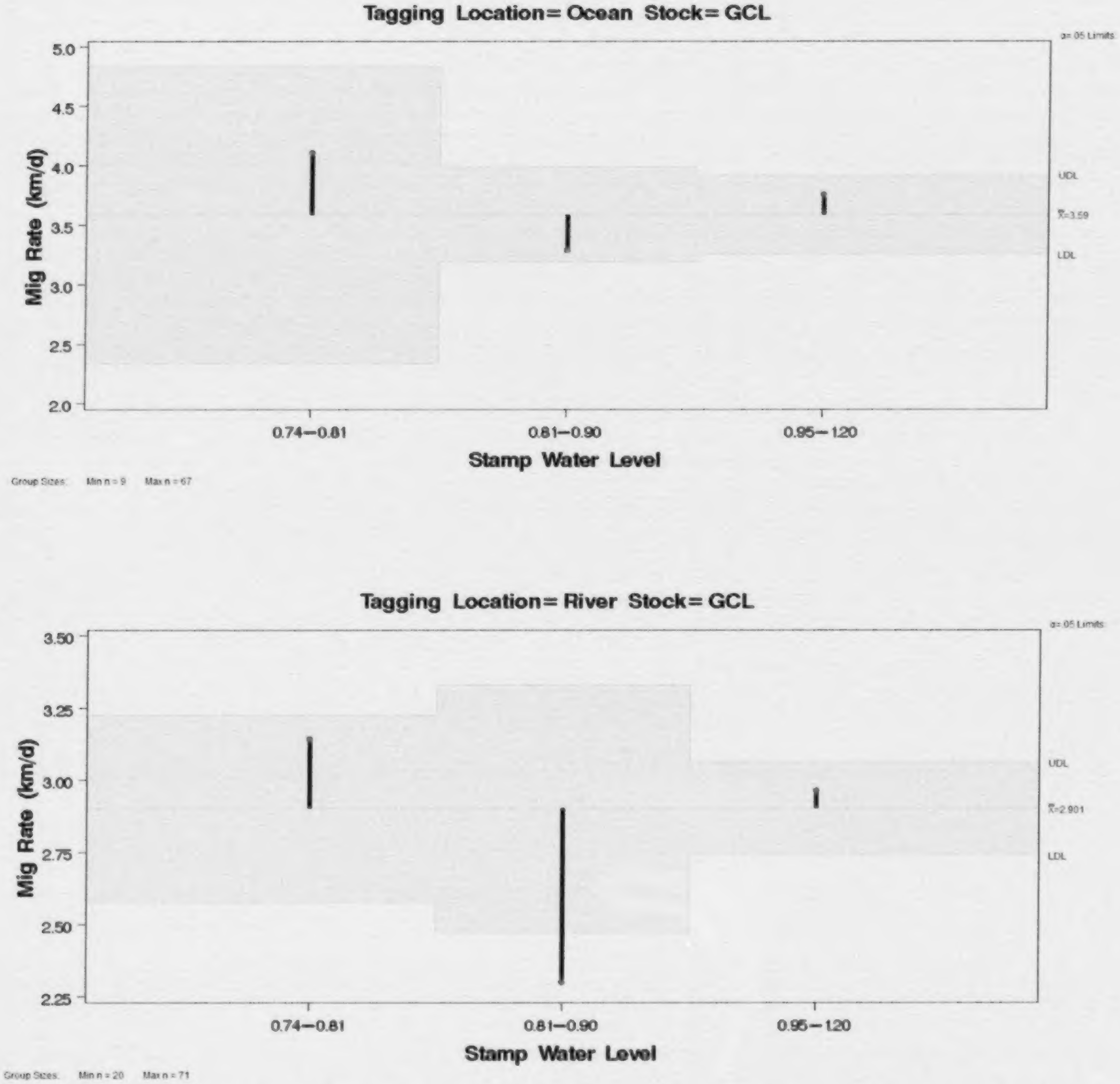


Figure 80. Needle plots of mean Sockeye migration rate (km/d) by category of 3-day moving average water temperature for river-tagged fish bound for Sproat Lake via the Somass River (top) and the Sproat River (bottom). Shaded blue areas denote upper and lower decision limits for the null hypothesis that the category mean is not significantly different from the overall average (horizontal line).

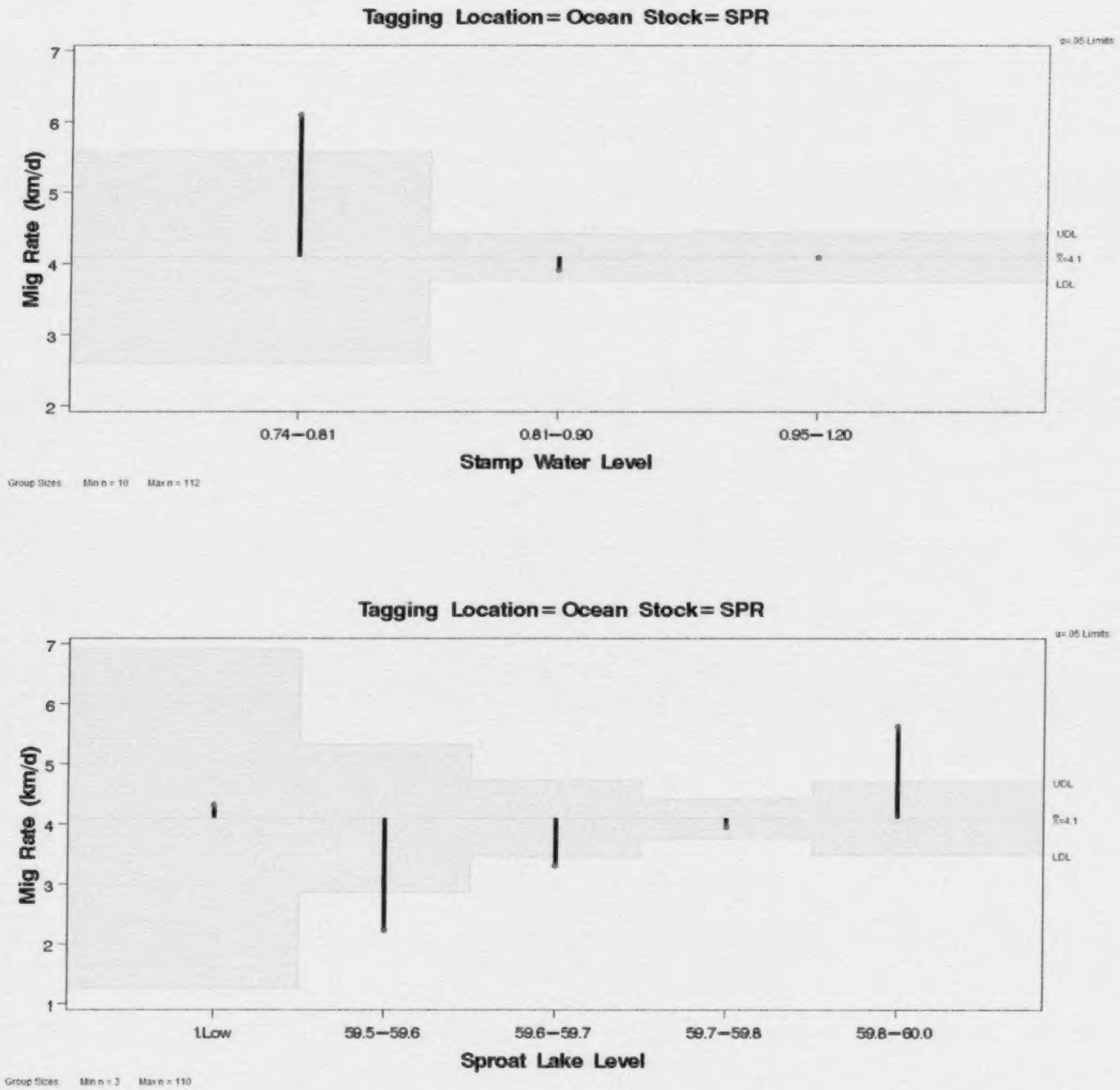


Figure 81. Needle plots of mean Sockeye migration rate (km/d) by high/low category of Stamp (top) and Sproat (bottom) water level for ocean-tagged fish bound for Sproat Lake. Shaded blue areas denote upper and lower decision limits for the null hypothesis that the category mean is not significantly different from the overall average (horizontal line).

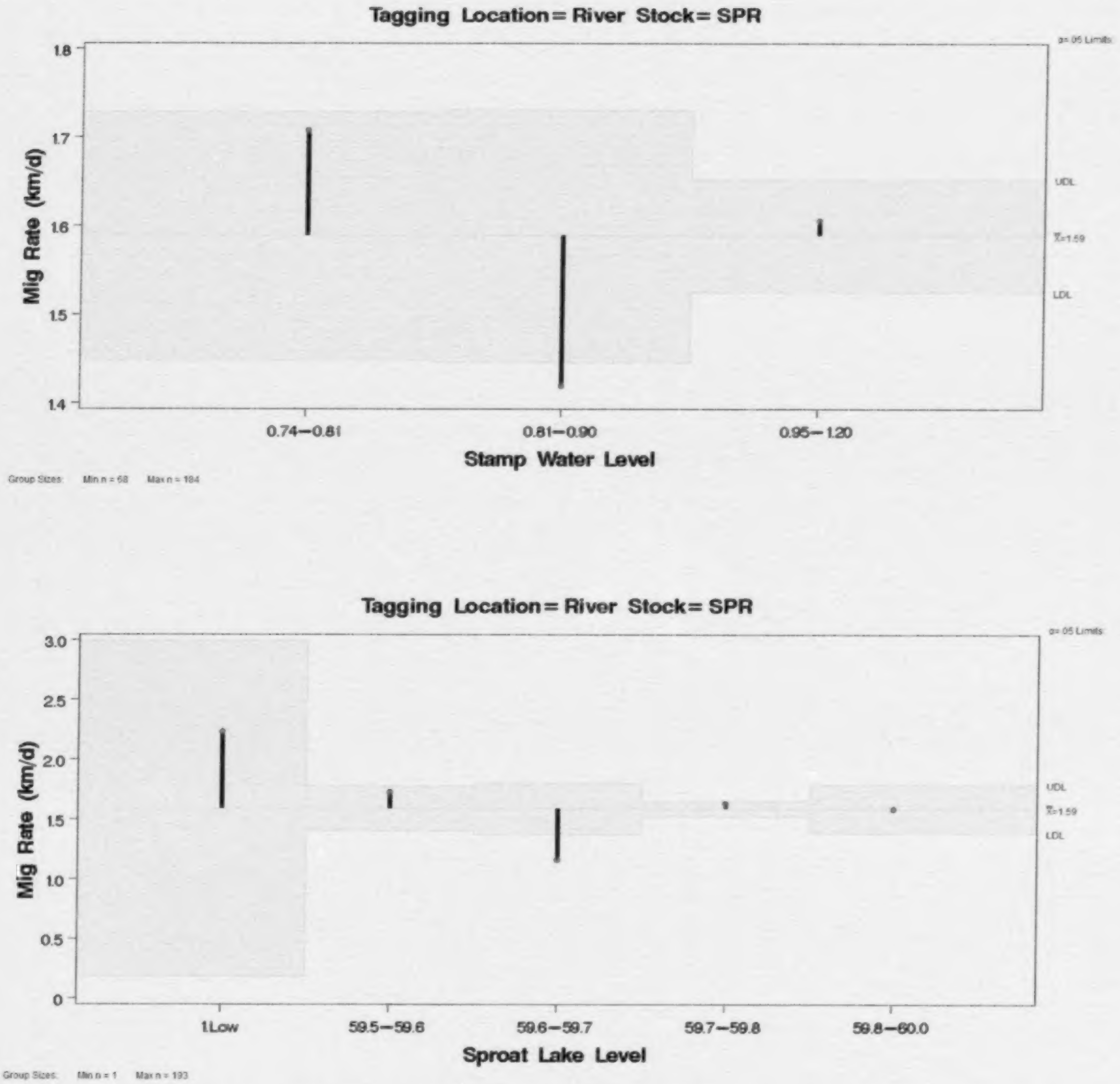


Figure 82. Needle plots of mean Sockeye migration rate (km/d) by high/low category of Stamp (top) and Sproat (bottom) water level for river-tagged fish bound for Sproat Lake. Shaded blue areas denote upper and lower decision limits for the null hypothesis that the category mean is not significantly different from the overall average (horizontal line).

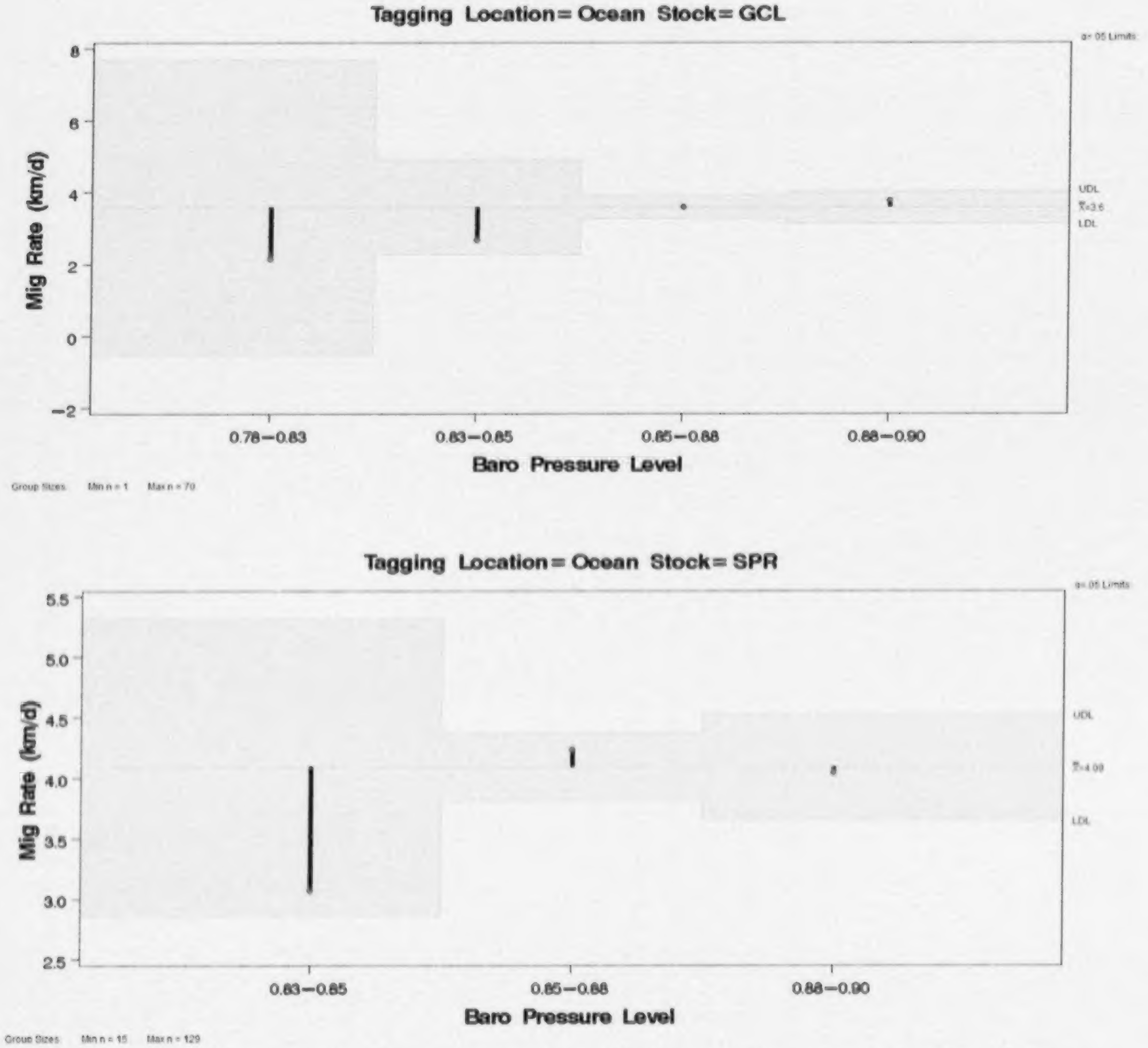
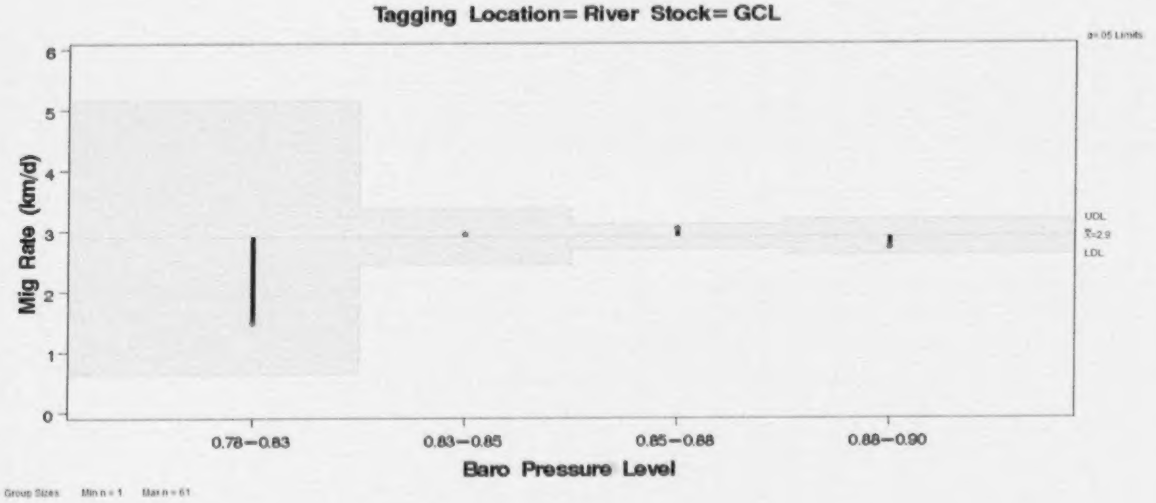


Figure 83. Needle plots of mean Sockeye migration rate (km/d) by multi-day barometric pressure index category for ocean-tagged fish bound for Great Central (top) and Sproat (bottom) lakes. Shaded blue areas denote upper and lower decision limits for the null hypothesis that the category mean is not significantly different from the overall average (horizontal line).



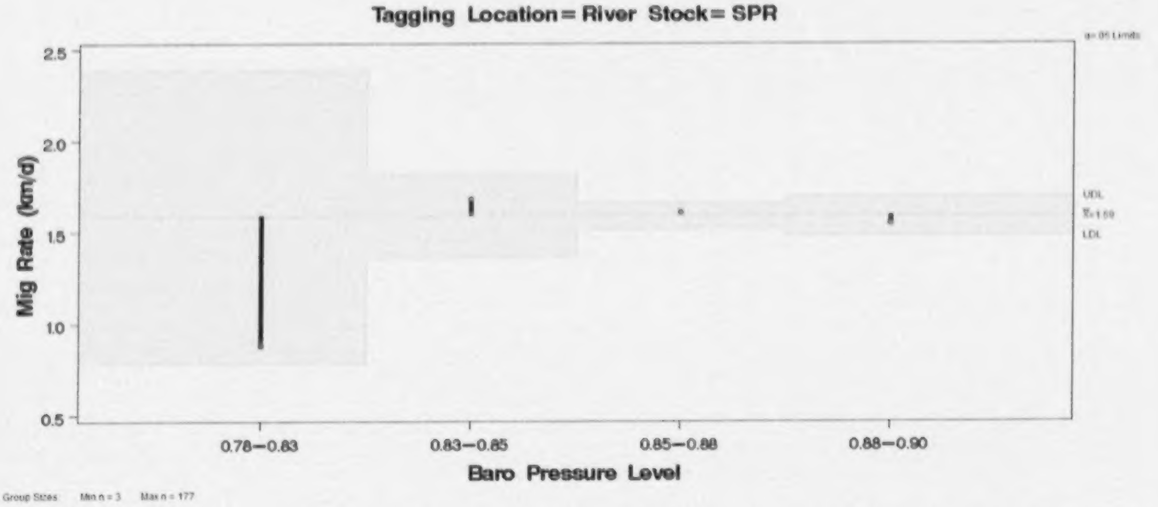


Figure 84. Needle plots of mean Sockeye migration rate (km/d) by multi-day barometric pressure index category for river-tagged fish bound for Great Central (top) and Sproat (bottom) lakes. Shaded blue areas denote upper and lower decision limits for the null hypothesis that the category mean is not significantly different from the overall average (horizontal line).

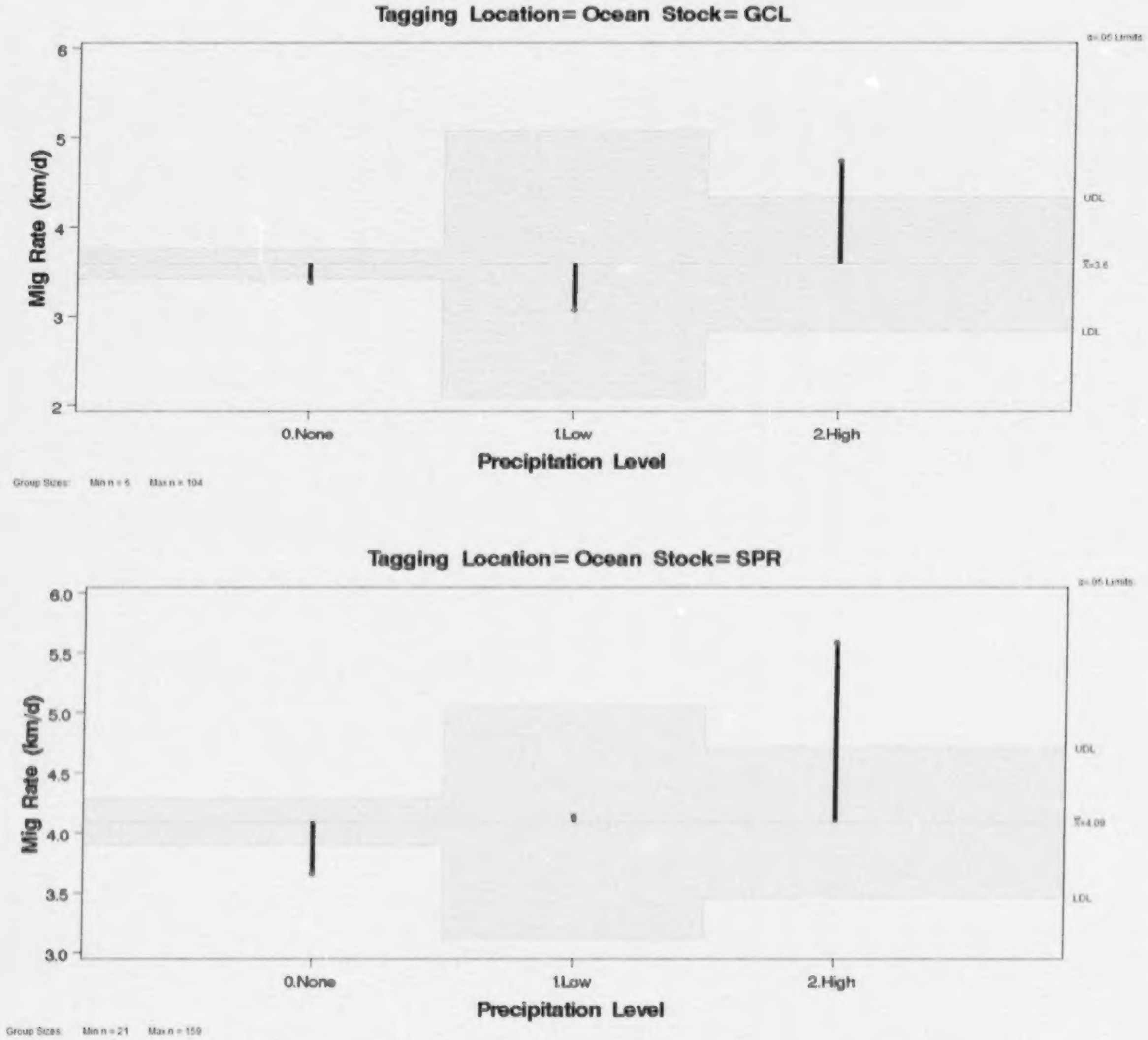


Figure 85. Needle plots of mean Sockeye migration rate (km/d) by multi-day precipitation index category for ocean-tagged fish bound for Great Central (top) and Sproat (bottom) lakes. Shaded blue areas denote upper and lower decision limits for the null hypothesis that the category mean is not significantly different from the overall average (horizontal line).

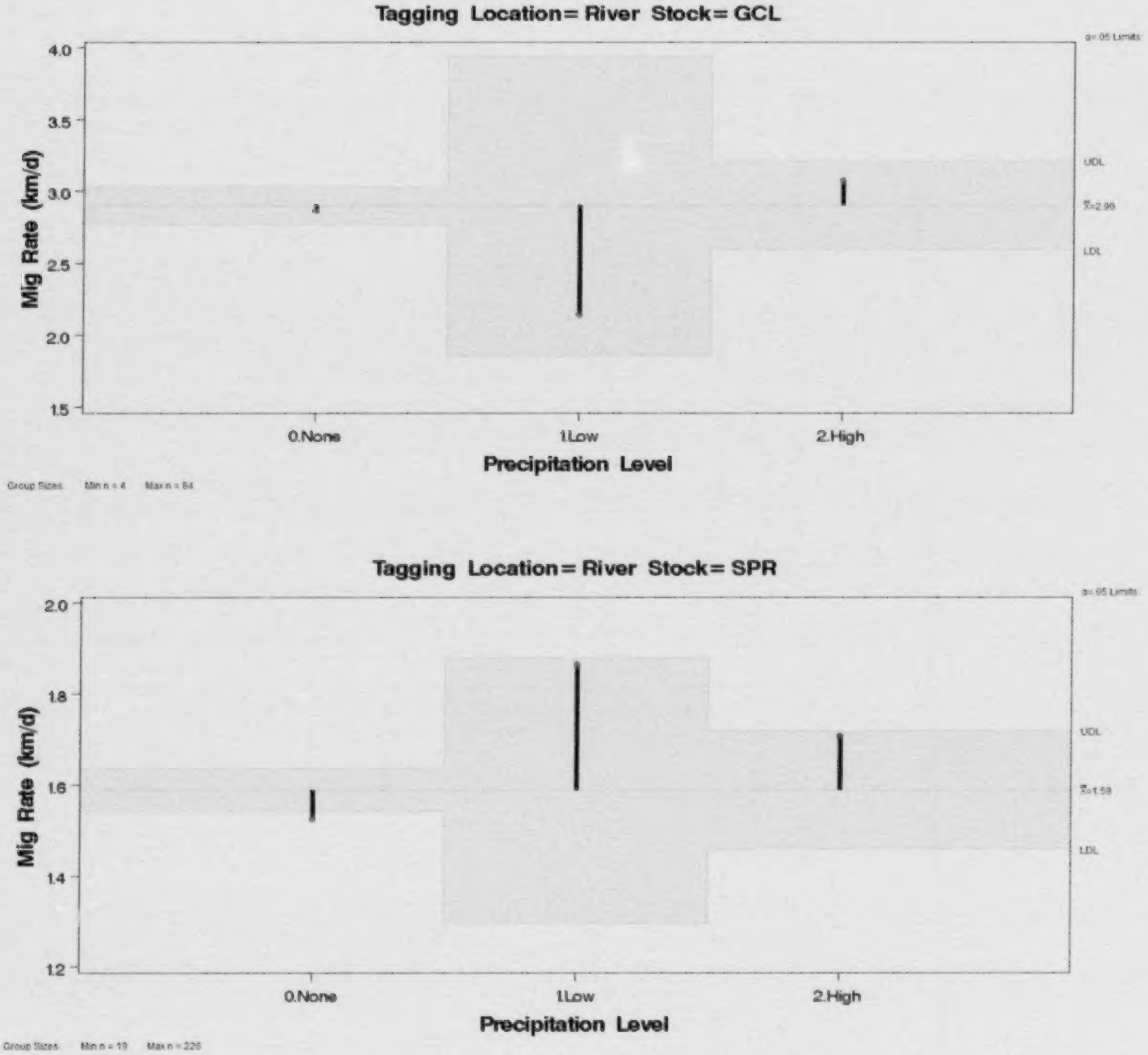


Figure 86. Needle plots of mean Sockeye migration rate (km/d) by multi-day precipitation index category for river-tagged fish bound for Great Central (top) and Sproat (bottom) lakes. Shaded blue areas denote upper and lower decision limits for the null hypothesis that the category mean is not significantly different from the overall average (horizontal line).

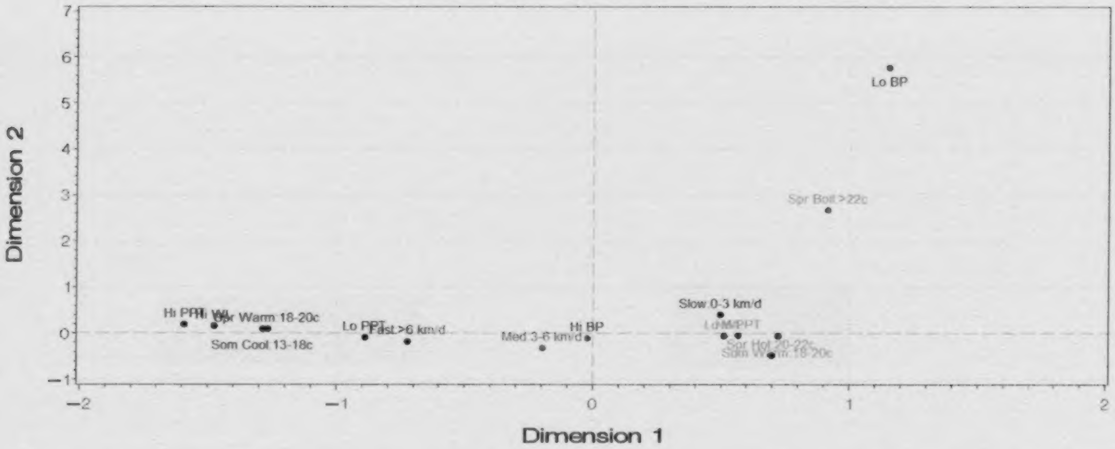


Figure 87. Multiple correspondence analysis for ocean-tagged Sproat-bound fish travel rates (km/d) categories (0-3, 3-6, and >6 km/d) in association with environmental variable categories in the Somass/Sproat waterbodies. Dimension 1 defined by "cool, wet" conditions to the left and "warm, dry" conditions to the right. Top fish travel rates are associated with "cool, wet" categories (yellow box to the left), while slowest travel rates are associated with "warm, dry" conditions (yellow box to the right).

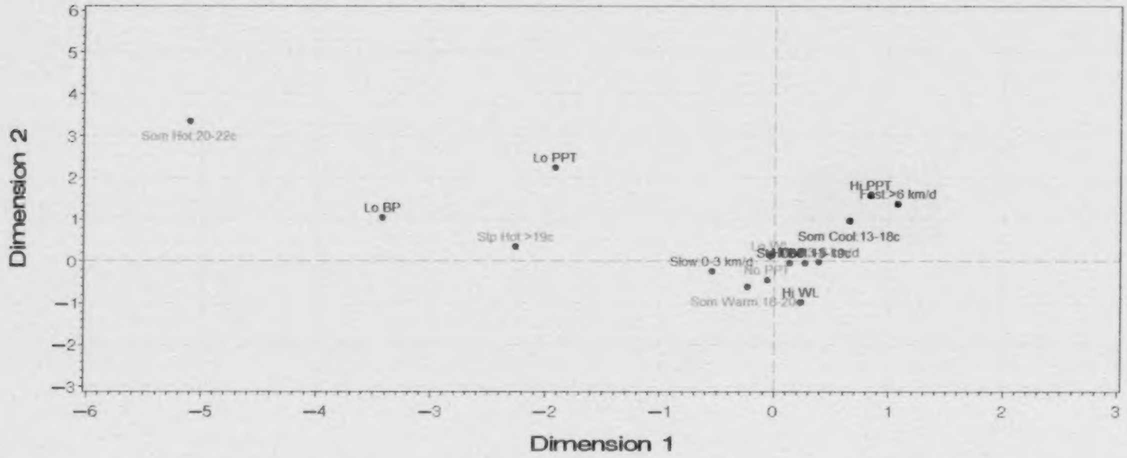


Figure 88. Multiple correspondence analysis for ocean-tagged GCL-bound fish travel rates (km/d) categories (0-3, 3-6, and >6 km/d) in association with environmental variable categories in the Somass/Stamp waterbodies. Top fish travel rates are associated with cool Somass conditions and precipitation (yellow box, upper right quadrant), while slowest travel rates are weakly associated with "warm, dry" conditions near the plot centroid (0,0: zone of low association).

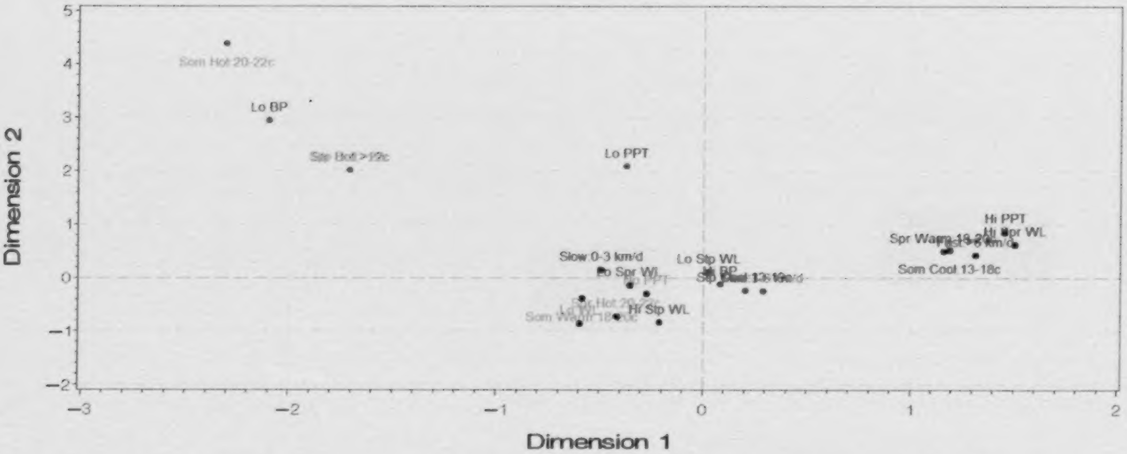


Figure 89. Multiple correspondence analysis for ocean-tagged GCL-bound fish travel rates (km/d) categories (0-3, 3-6, and >6 km/d) in association with environmental variable categories in the Somass/Stamp/Sproat waterbodies. Similar to Figure 88, but with more definition in dimension 1 due to incorporation of Sproat system conditions. Top GCL fish travel rates are associated with "cool, wet" conditions (yellow box to the right), while slowest travel rates are weakly associated with "warm, dry" conditions (yellow box to the left).

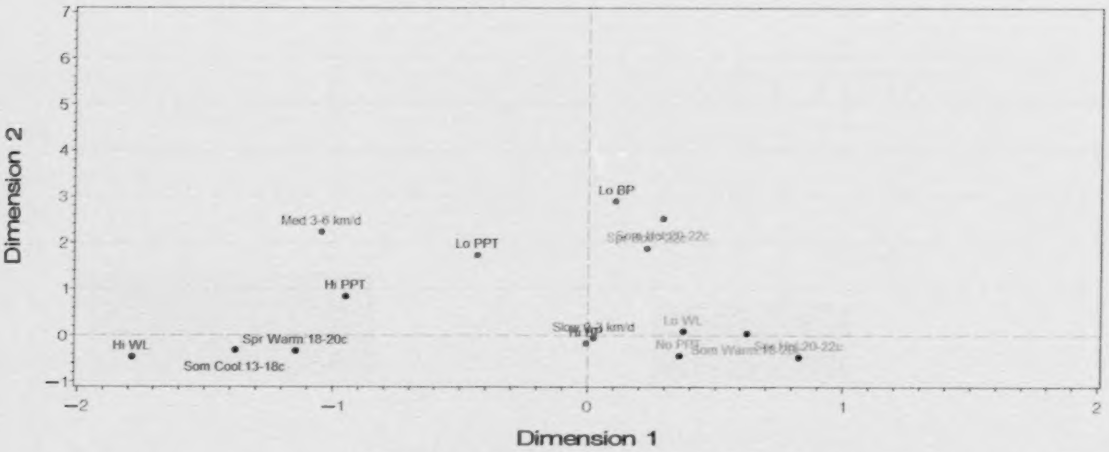


Figure 90. Multiple correspondence analysis for river-tagged Sproat-bound fish travel rates (km/d) categories (0-3, 3-6, and >6 km/d) in association with environmental variable categories in the Somass/Sproat waterbodies. Dimension 1 defined by "cool, wet" conditions to the left and "warm, dry" conditions to the right. Sproat fish travel rates (blue) show little or no association with environmental conditions at this stage of migration.

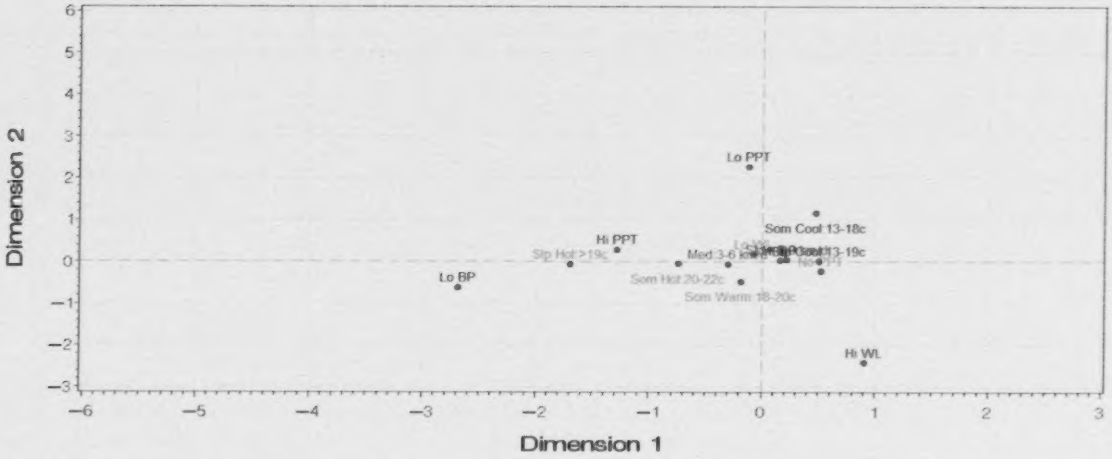


Figure 91. Multiple correspondence analysis for river-tagged GCL-bound fish travel rates (km/d) categories (0-3, 3-6, and >6 km/d) in association with environmental variable categories in the Somass/Stamp waterbodies. Dimensions not well-defined. GCL fish travel rates (blue) show little or no association with environmental conditions at this stage of migration.

TABLES

Date	Barometric Pressure (mm)	Sproat River Temp (°C)	Somass River Water Temperature (°C)	Air temperature at 14:00 (°C)
1-Jul-10	0.84	18.2	15.9	13.2
6-Jul-10	0.92	19.2	16.7	22.2
8-Jul-10	0.85	20.3	17.0	29.1
13-Jul-10	0.90	20.6	19.7	19.0
21-Jul-10	0.84	22.1	18.3	25.1
4-Aug-10	0.86	23.4	19.6	26.3
11-Aug-10	0.85	22.7	19.2	23.8

Table 1. Mean daily values for environmental conditions during in-river tagging operations.

Deployment Location	Sensor depth (m)	Deployment Date-Time	Sampling Interval
Ash River at Moran Creek (old WSC gauge), just below confluence on right bank upstream of WSC gauge	1.5	28-Jul-08	15 min
Sproat Above Somass confluence	1.0	29-Jul-08	15 min
Below Sproat Lake outlet - on right bank of bridge upstream of Tofino Hwy bridge (hanging off underside)	1.0	24-Mar-09	15 min
Stamp Above Somass confluence	1.5	29-Jul-08	15 min
Papermill Dam, City of Alberni concrete intake structure	1.5	29-Jul-08	15 min
Ash River under Ash MI Bridge US Dickson Lake, (RB)	1.0	14-May-09	15 min
Stamp River below Ash River, Moneys Pool, (LB)	0.5	14-May-09	15 min

Table 2. Data logger deployments in the Somass watershed, 2008-2010.

Locations	Pill Point	Chup Point	Coyote Bluff	Poca-hontas Point	Somass Mouth	Papermill Dam	Sproat Confluence	Sproat Falls	Stamp Falls
Pill Pt									
Chup Pt	4.4								
Limestone Pt	5.6	1.3							
Coyote Bluff	7.7	3.4							
Pochahontas Pt	9.6	5.3	1.9						
Somass Mouth	40.4	36.1	32.7	30.8					
Clutesi Marina	43.2	38.8	35.5	33.6	2.8				
Silver Bridge	45.7	41.3	38.0	36.1	5.3				
Papermill Dam	46.9	42.5	39.2	37.3	6.5				
Sproat Confluence	50.7	46.4	43.0	41.1	10.3	3.9			
Sproat Hobo #1					11.3	4.8	1.0		
Sproat Falls	52.7	48.4	45.0	43.1	12.3	5.9	2.0		
Sproat Hobo #2					12.5	6.0	2.2	0.2	
Sproat Lake Outlet					12.9	6.4	2.6	0.6	
Stamp Hobo					10.6	4.1	0.3		
Stamp Falls	57.1	52.7	49.4	47.5	16.7	10.2	6.4	8.4	
Great Central Lake	70.6	66.2	62.9	61.0	30.2	23.7	19.9	21.9	13.5

Table 3. Distance matrix (km) between tagging sites, detection locations, and other key landmarks.

		Water Temperature Variates		
Statistic	**Environmental Variate**	**Somass River**	**Stamp River**	**Sproat River**
MEAN		19.25	18.84	21.61
STD		1.27	1.36	1.40
N		62	62	62
CORR	**Stamp Water Level**	-0.43	-0.52	-0.27
CORR	STP_Level_2dBMA	-0.44	-0.53	-0.27
CORR	STP_Level_3dBMA	-0.45	-0.54	-0.28
CORR	STP_Level_4dBMA	-0.47	-0.56	-0.29
CORR	STP_Level_7dBMA	-0.54	-0.63	-0.34
CORR	**Stamp Water Temp**	0.98		0.75
CORR	STP_Temp_2dBMWT	0.95		0.74
CORR	STP_Temp_3dBMWT	0.87		0.72
CORR	STP_Temp_4dBMWT	0.79		0.70
CORR	STP_Temp_7dBMWT	0.64		0.61
CORR	**Sproat Lake Level**	-0.59		-0.53
CORR	SPR_WL_2dBStd	-0.57		-0.46
CORR	SPR_WL_3dBStd	-0.55		-0.44
CORR	SPR_WL_4dBStd	-0.54		-0.43
CORR	SPR_WL_7dBStd	-0.52		-0.41
CORR	**Sproat River Level**	-0.54		-0.41
CORR	SPR_Flow_2dBMA	-0.54		-0.41
CORR	SPR_Flow_3dBMA	-0.54		-0.41
CORR	SPR_Flow_4dBMA	-0.54		-0.41
CORR	SPR_Flow_7dBMA	-0.54		-0.41
CORR	**Precipitation (LN Transform)**	-0.17	-0.12	-0.28
CORR	Log_PPT_2dBMT	-0.27	-0.20	-0.37
CORR	Log_PPT_3dBMT	-0.32	-0.26	-0.39
CORR	Log_PPT_4dBMT	-0.31	-0.24	-0.38
CORR	Log_PPT_7dBMT	-0.14	-0.05	-0.36
CORR	**Barometric Pressure**	-0.45	-0.49	-0.30
CORR	Baro_2dBMA	-0.45	-0.48	-0.32
CORR	Baro_3dBMA	-0.39	-0.42	-0.33
CORR	Baro_4dBMA	-0.33	-0.34	-0.34
CORR	Baro_7dBMA	-0.37	-0.38	-0.45
CORR	**Air Temperature**	0.62	0.57	0.57
CORR	AirT_10dBMAT	0.50	0.44	0.71
CORR	AirT_10dCMAT	**0.63**	0.53	**0.74**

Table 4. Spearman rank correlation coefficients for daily mean Somass, Stamp, and Sproat River water temperature as a function of daily mean values of environmental variates (Stamp River water level and temperature, Sproat Lake and Sproat River water levels, precipitation, barometric air pressure, and air temperature) and corresponding multi-day moving average indices. July and August only.

		Stock					
		GCL			SPR		
		Start	Count	Pct	Start	Count	Pct
Month	Week						
JUN	24	21JUN	7	46.7	18JUN	8	53.3
	25	23JUN	8	36.4	23JUN	14	63.6
	26	30JUN	7	20.6	30JUN	27	79.4
	Monthly	21JUN	22	31.0	18JUN	49	69.0
JUL	Week						
	26	04JUL	23	27.7	04JUL	60	72.3
	27	07JUL	60	30.3	07JUL	138	69.7
	28	14JUL	88	33.7	14JUL	173	66.3
	29	21JUL	32	28.8	21JUL	79	71.2
	30	29JUL	12	32.4	28JUL	25	67.6
	Monthly	04JUL	215	31.2	04JUL	475	68.8
AUG	Week						
	31	05AUG	23	47.9	05AUG	25	52.1
	32	11AUG	10	26.3	11AUG	28	73.7
	33	21AUG	3	42.9	21AUG	4	57.1
	34	28AUG	4	57.1	27AUG	3	42.9
	35	01SEP	6	60.0	01SEP	4	40.0
	Monthly	05AUG	46	41.8	05AUG	64	58.2
SEP	35	04SEP	6	66.7	04SEP	3	33.3
	36	09SEP	5	62.5	10SEP	3	37.5
	37	18SEP	1	50.0	21SEP	1	50.0
	38				25SEP	1	100.0
	Monthly	04SEP	12	60.0	04SEP	8	40.0
Total		21JUN	295	33.1	18JUN	596	66.9

Table 5. Weekly PIT tag detections and stock composition as a percent of weekly total tags detected at Stamp (GCL stock) and Sproat fishways.

	Ocean Tagging Date (Argent 1)							**River Tagging Date (Papermill Dam)**							
	14-Jun	21-Jun	28-Jun	5-Jul	12-Jul	19-Jul	**Tot**	1-Jul	6-Jul	8-Jul	13-Jul	21-Jul	4-Aug	11-Aug	**Tot**
Tags	158	289	396	318	219	107	**1487**	128	199	49	339	297	249	61	**1322**
STP	24	33	56	35	19	10	**177**	14	27	4	50	11	22	9	**128**
SPR	25	49	88	49	38	9	**258**	49	80	8	115	34	31	22	**317**
GCL	20	26	42	31	12	3	**134**	10	22	3	35	8	11	3	**89**
All	69	108	186	115	69	22	**569**	73	129	15	200	53	64	34	**534**
%	31.0	28.4	36.4	26.4	26.0	17.8	**29.3**	49.2	53.8	24.5	48.7	15.2	213	50.8	**33.7**

Table 6. Weekly numbers and percentage of PIT tags detected in the Somass watershed for ocean-tagged fish and river-tagged fish.

	Fishway Swim Speeds (meters/min)							
	SPR				STP			
	Tags	Min	Med	Max	Tags	Min	Med	Max
Week Ending								
04Jun	1	0.9	0.9	0.9				
18Jun	1	24.5	24.5	24.5				
25Jun	5	0.8	2.8	4.6	10	1.3	12.3	34.8
03Jul	10	0.7	2.9	10.3	6	1.8	15.9	24.5
10Jul	44	0.3	2.3	20.5	47	1.0	6.8	27.0
17Jul	40	0.5	3.7	20.5	40	1.0	8.5	34.8
24Jul	20	0.4	2.0	16.9	27	1.3	12.6	28.4
31Jul	9	0.7	1.7	14.7	12	0.9	4.2	24.0
07Aug	4	0.5	2.8	4.4	12	2.0	15.0	27.7
14Aug	6	0.8	0.9	1.5	8	0.5	9.5	25.1
21Aug					3	0.9	3.1	26.3
28Aug					2	2.4	2.6	2.8
04Sep	3	1.1	2.3	2.9	2	18.3	20.2	22.0
11Sep	1	1.4	1.4	1.4	1	8.6	8.6	8.6
18Sep					1	1.4	1.4	1.4
25Sep	1	1.5	1.5	1.5				
All	145	0.3	2.3	24.5	171	0.5	9.3	34.8

Table 7. Weekly minimum, median and maximum fish swim speeds for tags detected at Sproat and Stamp fishways. Restricted to fish that successfully ascended the fishway on the first attempt (i.e., tags detected only once at each antenna in the array).

```
                         Fishway Transit Speed
                            Compare Sites

                        The NPAR1WAY Procedure

               Analysis of Variance for Variable Transit_Speed
                        Classified by Variable Site

               Site                  N                    Mean

               SPR                 145                4.652660
               STP                 171               11.494097

  Source     DF    Sum of Squares    Mean Square    F Value    Pr > F

  Among       1       3672.583857    3672.583857    62.2566    <.0001
  Within    314      18523.194085      58.991064

                          Kruskal-Wallis Test

                     Chi-Square                 58.7448
                     DF                               1
                     Pr > Chi-Square             <.0001
```

Table 8. Comparison of fish swim speeds for tags detected at Sproat and Stamp fishways. Restricted to tags detected only once at each antenna in the array.

```
                               Fishway Transit Speed
                               Compare Sites By Week

Week      _VAR_            _MSA_      _MSE_        _F_       P_F        _KW_    DF_KW      P_KW

25Jun   Transit_Speed     571.506    103.059      5.545   0.03491     5.4150      1     0.01996
03Jul   Transit_Speed     364.295     42.994      8.473   0.01139     3.0118      1     0.08266
10Jul   Transit_Speed     708.015     50.848     13.924   0.00033    14.6237      1     0.00013
17Jul   Transit_Speed     690.542     68.657     10.058   0.00217     8.4733      1     0.00360
24Jul   Transit_Speed     622.246     58.908     10.563   0.00219    10.9809      1     0.00092
31Jul   Transit_Speed     114.552     44.542      2.572   0.12528     2.6717      1     0.10215
07Aug   Transit_Speed     392.128     43.693      8.975   0.00963     7.1598      1     0.00746
14Aug   Transit_Speed     316.056     51.671      6.117   0.02932     3.2667      1     0.07070
04Sep   Transit_Speed     390.675      2.890    135.202   0.00137     3.0000      1     0.08326
```

Table 9. Significance of differences in fish swim speeds for tags detected at Sproat and Stamp fishways by week. Restricted to tags detected only once at each antenna in the array. In all cases, swim speeds at Stamp were 2-5x faster. Significance ranged from weak (P < 0.10) to strong (P < 0.01).

```
                               Fishway Transit Speed
                               Compare Weeks By Site

Site      _VAR_          _MSA_      _MSE_       _F_        P_F        _KW_    DF_KW      P_KW

SPR    Transit_Speed    51.6615    25.0968    2.05849    0.02390     8.9250     12     0.70932
STP    Transit_Speed    78.7361    86.3649    0.91167    0.53679    11.3121     12     0.50237
```

Table 10. Significance of differences in fish swim speeds between weeks for tags detected at Sproat and Stamp fishways by site. Restricted to tags detected only once at each antenna in the array. Although parametric analysis indicated significant differences between weeks at the Sproat fishway (P_F = 0.02), the more robust Kruskal-Wallis comparison did not indicate significance (P = 0.70).

	Fishway Swim Speeds (meters/min)							
	SPR				STP			
	Tags	Min	Med	Max	Tags	Min	Med	Max
Week Ending								
04Jun	1	0.6	0.6	0.6				
11Jun	1	13.0	13.0	13.0				
25Jun	5	0.6	1.9	11.1	1	5.1	5.1	5.1
03Jul	13	1.1	2.4	10.7	2	7.6	9.9	12.3
10Jul	70	0.4	1.5	17.1	14	0.6	6.5	27.0
17Jul	63	0.2	1.2	15.6	18	0.9	4.5	32.7
24Jul	34	0.4	1.3	13.1	6	1.1	4.8	10.8
31Jul	14	0.3	1.4	30.0	2	15.7	22.4	29.2
07Aug	13	0.8	1.3	19.8	6	0.4	16.1	20.4
14Aug	10	0.4	1.0	1.6	2	3.9	4.8	5.6
21Aug	4	1.0	1.7	4.3	1	0.8	0.8	0.8
28Aug	2	1.8	2.6	3.5				
04Sep	4	1.1	1.2	3.6	2	1.8	6.1	10.4
All	234	0.2	1.4	30.0	54	0.4	7.0	32.7

Table 11. Weekly minimum, median and maximum fish swim speeds for tags detected at Sproat and Stamp fishways. Restricted to fish that successfully ascended the fishway after multiple attempts (i.e., tags detected multiple times at antenna #1, but only once at antenna #2).

```
                          Fishway Transit Speed
                              Compare Sites

                          The NPAR1WAY Procedure

                Analysis of Variance for Variable Transit_Speed
                         Classified by Variable Site

                Site                  N                   Mean

                SPR                 234               2.724073
                STP                  54              10.006064

  Source      DF    Sum of Squares    Mean Square     F Value    Pr > F

  Among        1       2326.576805    2326.576805     89.1068    <.0001
  Within     286       7467.451439      26.109970

                            Kruskal-Wallis Test

                     Chi-Square                 44.2595
                     DF                               1
                     Pr > Chi-Square             <.0001
```

Table 12. Comparison of fish swim speeds for tags detected at Sproat versus Stamp fishways. Restricted to tags detected multiple times at Antenna #1 but only once at Antenna #2.

```
                          Fishway Transit Speed
                              Compare Sites

                          The NPAR1WAY Procedure

                Analysis of Variance for Variable A1_Minutes
                       Classified by Variable Site

                Site                 N                  Mean

                SPR                234             12.335320
                STP                 54              8.145368

Source      DF    Sum of Squares    Mean Square     F Value    Pr > F

Among        1        770.624069     770.624069      1.0650    0.3030
Within     286     206950.250954     723.602276

                          Kruskal-Wallis Test

                     Chi-Square               12.5275
                     DF                             1
                     Pr > Chi-Square           0.0004
```

Table 13. Comparison of Antenna #1 transit times (minutes) for tags detected at Sproat versus Stamp fishways. Restricted to tags detected multiple times at Antenna #1 but only once at Antenna #2.

	Fishway Swim Speeds (meters/min)							
	SPR				STP			
	Tags	Min	Med	Max	Tags	Min	Med	Max
Week Ending								
25Jun	4	0.6	0.9	3.1	2	1.7	6.2	10.8
03Jul	7	0.1	0.7	3.1	2	0.9	1.7	2.5
10Jul	16	0.2	0.9	17.2	10	0.6	1.8	25.7
17Jul	21	0.1	1.1	26.6	14	0.2	1.2	29.2
24Jul	10	0.5	2.5	9.6	10	0.3	1.7	7.0
31Jul	5	0.3	0.4	2.3	4	0.7	1.3	2.0
07Aug	3	1.3	4.1	5.4	5	1.1	7.0	11.2
14Aug	3	0.6	0.7	0.9	2	2.9	4.5	6.2
04Sep	1	2.7	2.7	2.7	4	0.5	2.1	21.2
11Sep	1	0.5	0.5	0.5	6	0.3	1.1	10.1
18Sep					1	0.9	0.9	0.9
All	71	0.1	0.9	26.6	60	0.2	1.8	29.2

Table 14. Weekly minimum, median and maximum fish swim speeds for tags detected at Sproat and Stamp fishways. Restricted to fish that successfully exited the fishway after multiple fall-backs within the fishway (i.e., tags detected only once at antenna #1, but multiple times at antenna #2).

```
                         Fishway Transit Speed
                             Compare Sites

                        The NPAR1WAY Procedure

             Analysis of Variance for Variable Transit_Speed
                       Classified by Variable Site

             Site                  N                    Mean

             SPR                  71                2.750381
             STP                  60                4.477880

Source      DF    Sum of Squares    Mean Square      F Value    Pr > F

Among        1         97.045108      97.045108       3.1824    0.0768
Within     129       3933.813715      30.494680

                          Kruskal-Wallis Test

                  Chi-Square                  4.2164
                  DF                               1
                  Pr > Chi-Square             0.0400
```

Table 15. Comparison of fish swim speeds for tags detected at Sproat versus Stamp fishways. Restricted to tags detected only once at Antenna #1 but multiple times at Antenna #2 (i.e., fall-backs within the fishway).

```
                         Fishway Transit Speed
                             Compare Sites

                        The NPAR1WAY Procedure

              Analysis of Variance for Variable A2_Minutes
                       Classified by Variable Site

             Site                  N                    Mean

             SPR                  71               12.756568
             STP                  60               11.450274

Source      DF    Sum of Squares    Mean Square      F Value    Pr > F

Among        1         55.490759      55.490759       0.1090    0.7418
Within     129      65684.209774     509.179921

                          Kruskal-Wallis Test

                  Chi-Square                  0.6878
                  DF                               1
                  Pr > Chi-Square             0.4069
```

Table 16. Comparison of Antenna #2 transit times (minutes) for tags detected at Sproat versus Stamp fishways. Restricted to tags detected only once at Antenna #1 but multiple times at Antenna #2 (i.e., fall-backs within the fishway).

```
            Transit_Speed by WaterT
Controlling for Migrants=Pmax(200+)

Transit_Speed(Speed Between Antennas (m/min))
             WaterT(Temp Group)

Frequency|
Percent  |
Row Pct  |
Col Pct  |<20c    |>20c    |  Total
---------+--------+--------+
Low      |      4 |     12 |     16
         |   8.70 |  26.09 |  34.78
         |  25.00 |  75.00 |
         |  20.00 |  46.15 |
---------+--------+--------+
Med      |      6 |     13 |     19
         |  13.04 |  28.26 |  41.30
         |  31.58 |  68.42 |
         |  30.00 |  50.00 |
---------+--------+--------+
High     |     10 |      1 |     11
         |  21.74 |   2.17 |  23.91
         |  90.91 |   9.09 |
         |  50.00 |   3.85 |
---------+--------+--------+
Total          20       26       46
            43.48    56.52   100.00
```

```
Statistics for Transit_Speed by WaterT
       Controlling for Migrants=Pmax(200+)

Statistic                     DF       Value      Prob
------------------------------------------------------
Chi-Square                     2     13.3877    0.0012
Likelihood Ratio Chi-Square    2     14.5891    0.0007
Mantel-Haenszel Chi-Square     1     12.3167    0.0004
Phi Coefficient                       0.5395
Contingency Coefficient               0.4748
Cramer's V                            0.5395

      Mantel-Haenszel Chi-Square Test
      ---------------------------------------
      Chi-Square                     12.3167
      DF                                   1
      Asymptotic Pr >  ChiSq          0.0004
      Exact      Pr >= ChiSq       3.055E-04

      Likelihood Ratio Chi-Square Test
      ---------------------------------------
      Chi-Square                     14.5891
      DF                                   2
      Asymptotic Pr >  ChiSq          0.0007
      Exact      Pr >= ChiSq          0.0015
```

Table 17. Non-parametric chi-square frequency analysis of PIT tag swim speed categories between Sproat fishway antennas #1 and #2, at temperatures above or below 20°C threshold, stratified by migrant density **(>200** fish per hour). Indicates that high swim speeds predominated only at temperatures below 20°C; while low-to-medium swim speeds predominated above 20C (P = .0012; N=46).

```
            Transit_Speed by WaterT
Controlling for Migrants=P90(0-200)

Transit_Speed(Speed Between Antennas (m/min))
             WaterT(Temp Group)

Frequency|
Percent  |
Row Pct  |
Col Pct  |<20c    |>20c    |  Total
---------+--------+--------+
Low      |     11 |     25 |     36
         |  12.22 |  27.78 |  40.00
         |  30.56 |  69.44 |
         |  30.56 |  46.30 |
---------+--------+--------+
Med      |     16 |     22 |     38
         |  17.78 |  24.44 |  42.22
         |  42.11 |  57.89 |
         |  44.44 |  40.74 |
---------+--------+--------+
High     |      9 |      7 |     16
         |  10.00 |   7.78 |  17.78
         |  56.25 |  43.75 |
         |  25.00 |  12.96 |
---------+--------+--------+
Total          36       54       90
            40.00    60.00   100.00

        Frequency Missing = 1
```

```
Statistics for Transit_Speed by WaterT
       Controlling for Migrants=P90(0-200)

Statistic                     DF       Value      Prob
------------------------------------------------------
Chi-Square                     2      3.1686    0.2051
Likelihood Ratio Chi-Square    2      3.1683    0.2051
Mantel-Haenszel Chi-Square     1      3.0048    0.0830
Phi Coefficient                       0.1876
Contingency Coefficient               0.1844
Cramer's V                            0.1876

      Mantel-Haenszel Chi-Square Test
      ---------------------------------------
      Chi-Square                      3.0048
      DF                                   1
      Asymptotic Pr >  ChiSq          0.0830
      Exact      Pr >= ChiSq          0.0898

      Likelihood Ratio Chi-Square Test
      ---------------------------------------
      Chi-Square                      3.1683
      DF                                   2
      Asymptotic Pr >  ChiSq          0.2051
      Exact      Pr >= ChiSq          0.2196
```

Table 18. Non-parametric chi-square frequency analysis of PIT tag swim speed categories between Sproat fishway antennas #1 and #2, at temperatures above or below 20°C threshold, stratified by migrant density **(<200** fish per hour). Indicates that weak (P = 0.08; N=90) between swim speeds and temperature thresholds.

```
                                              Fishway Transit Speed

------------------------------------------------------------------ Site=SPR ------------------------------------------------------------------

                                            Spearman Correlation Coefficients
                                              Prob > |r| under H0: Rho=0
                                                Number of Observations

A1_Count                          PMD_Temp_3dBMWT             STP_Level_3dBMA             SPR_Temp_BCCF               STP_Level_4dBMA
                                               0.08068                    -0.07697                      0.07365                    -0.07345
                                               0.0881                      0.1026                       0.1196                      0.1193
                                                  448                         451                          448                         451

A1_Minutes                        Baro_7dBMA                  PMD_Temp_3dBMWT             SPR_Temp_BCCF               PMD_Temp_4dBMWT
Antenna 1 (min)                                0.07741                     0.07407                      0.07104                     0.06496
                                               0.1077                      0.1175                       0.1333                      0.1699
                                                  433                         448                          448                         448

Transit_Speed                     PMD_Temp_3dBMWT             STP_Temp_4dBMWT             PMD_Temp_4dBMWT             PMD_Temp_2dBMWT
Speed Between Antennas (m/min)                -0.16163                    -0.13595                     -0.13304                    -0.13110
                                               0.0006                      0.0040                       0.0048                      0.0055
                                                  447                         447                          447                         447

lavig_Speed                       PMD_Temp_3dBMWT             PMD_Temp_4dBMWT             STP_Temp_4dBMWT             Root4_PPT_2dBMT
ipeed Through Antennas (m/min)                -0.14547                    -0.11948                     -0.11858                     0.11215
                                               0.0020                      0.0115                       0.0121                      0.0249
                                                  447                         447                          447                         409

i2_Count                          STP_Level_4dBMA             STP_Level_3dBMA             STP_Level_2dBMA             Baro_7dBMA
                                               0.06378                     0.06189                      0.06134                    -0.05694
                                               0.1760                      0.1901                       0.1940                      0.2376
                                                  450                         450                          450                         432

i2_Minutes                        STP_Level_2dBMA             STP_Level_4dBMA             STP_Level_3dBMA             Baro_7dBMA
ntenna 2 (min)                                 0.06017                     0.05957                      0.05823                    -0.05394
                                               0.2027                      0.2072                       0.2177                      0.2633
                                                  450                         450                          450                         432


                                              Fishway Transit Speed                                                                     1

------------------------------------------------------------------ Site=STP ------------------------------------------------------------------

                                            Spearman Correlation Coefficients
                                              Prob > |r| under H0: Rho=0
                                                Number of Observations

A1_Count                          Log_PPT_3dBMT               Root4_PPT_3dBMT             Root4_PPT                   Log_PPT_2dBMT
                                              -0.13647                    -0.12236                     -0.11287                    -0.11277
                                               0.0205                      0.0386                       0.1282                      0.0559
                                                  288                         286                          183                         288

A1_Minutes                        Log_PPT_3dBMT               Root4_PPT_3dBMT             Log_PPT_2dBMT               Root4_PPT
Antenna 1 (min)                               -0.13184                    -0.11853                     -0.11173                    -0.10863
                                               0.0253                      0.0452                       0.0583                      0.1433
                                                  288                         286                          288                         183

Transit_Speed                     StampDailyDischargeEst      STP_Temp_4dBMWT             Log_PPT                     STP_Level_4dBMA
Speed Between Antennas (m/min)                 0.10314                    -0.09489                      0.09241                     0.08681
                                               0.0822                      0.1103                       0.1196                      0.1438
                                                  285                         285                          285                         285

Navig_Speed                       Log_PPT                     StampDailyDischargeEst      Root4_PPT_2dBMT             STP_Temp_4dBMWT
Speed Through Antennas (m/min)                 0.13486                     0.11874                      0.11502                    -0.10541
                                               0.0228                      0.0452                       0.0651                      0.0756
                                                  285                         285                          258                         285

A2_Count                          StampDailyDischargeEst      STP_WaterLevel              STP_Level_4dBMA             STP_Level_2dBMA
                                              -0.16681                    -0.13501                     -0.13376                    -0.12852
                                               0.0048                      0.0226                       0.0239                      0.0301
                                                  285                         285                          285                         285

A2_Minutes                        StampDailyDischargeEst      STP_WaterLevel              STP_Level_4dBMA             STP_Level_2dBMA
Antenna 2 (min)                               -0.15323                    -0.12558                     -0.12481                    -0.11916
                                               0.0096                      0.0341                       0.0352                      0.0444
                                                  285                         285                          285                         285
```

Table 19. Top Spearman rank correlation coefficients for fishway indicators for individual tags at Sproat fishway (top) and Stamp fishway (bottom) as a function of daily mean values of environmental variates (Stamp River water level and temperature, Sproat Lake and Sproat River water levels, precipitation, barometric air pressure, and air temperature) and corresponding multi-day moving average indices. Tag indicators: A1/A2 Count = number of times tag detected at antenna 1 or 2; A1/A2 Minutes = time in minutes between first and last detection at antenna 1 or 2; Transit Minutes = length of time between last detection at antenna 1 and first detection at antenna 2; Navig Minutes = length of time between first detection at antenna 1 and last detection at antenna 2. Significant independent environmental variates highlighted in yellow for each tag indicator type.

```
                                        Fishway Transit Speed

----------------------------------------------------------------- Site=SPR ------------------------------------------------------------

                                   Spearman Correlation Coefficients
                                      Prob > |r| under H0: Rho=0
                                       Number of Observations

Transit_Speed                        PMD_Temp_3dBMWT              STP_Temp_4dBMWT              PMD_Temp_4dBMWT              PMD_Temp_2dBMWT
Speed Between Antennas (m/min)                   -0.16163                     -0.13595                     -0.13304                     -0.13110
                                                   0.0006                       0.0040                       0.0048                       0.0055
                                                      447                          447                          447                          447

Transit_Speed                        Baro_2dBMA                   SPR_Flow_Lag0_4dBMF          SPR_Root4_Flow_Lag0_3dBMF    SPR_Flow_Lag0_7dBMF
Speed Between Antennas (m/min)                    0.11574                      0.10336                      0.10332                      0.10327
                                                   0.0161                       0.0283                       0.0284                       0.0285
                                                      432                          450                          450                          450

Transit_Speed                        SPR_Root4_Flow_Lag0_4dBMF    SPR_Flow_Lag0_3dBMF          SPR_Root4_Flow_Lag0_7dBMF    SPR_Flow_Lag0_2dBMF
Speed Between Antennas (m/min)                    0.10326                      0.10320                      0.10312                      0.10296
                                                   0.0285                       0.0286                       0.0287                       0.0290
                                                      450                          450                          450                          450

Transit_Speed                        SPR_Root4_Flow_Lag0_2dBMF    SPR_WL_Lag0_7dBMWL           SproatDailyDischarge         SPR_Root4_Flow
Speed Between Antennas (m/min)                    0.10242                      0.10226                      0.10149                      0.10149
                                                   0.0298                       0.0301                       0.0314                       0.0314
                                                      450                          450                          450                          450

Transit_Speed                        SPR_Temp_BCCF                SPR_WL_Lag0_3dBMWL           SPR_WL_Lag0_4dBMWL           Root4_PPT_2dBMT
Speed Between Antennas (m/min)                   -0.09998                      0.09887                      0.09349                      0.09344
                                                   0.0346                       0.0360                       0.0475                       0.0619
                                                      447                          450                          450                          400

Transit_Speed                        SPR_WL_Lag0_2dBMWL           SproatLakeLevel              PMD_Temp_BCCF                Log_PPT
Speed Between Antennas (m/min)                    0.08900                      0.08402                     -0.08327                      0.08063
                                                   0.0592                       0.0763                       0.0780                       0.0876
                                                      450                          446                          449                          450

Transit_Speed                        BARO                         Root4_PPT_4dBMT              SPR_Temp_7dBMWT              Root4_PPT_3dBMT
Speed Between Antennas (m/min)                    0.07996                      0.06899                     -0.06576                      0.06346
                                                   0.0970                       0.1449                       0.1651                       0.1804
                                                      432                          440                          447                          447

Transit_Speed                        SPR_Temp_2dBMWT              Baro_7dBMA                   SPR_Temp_4dBMWT              Log_PPT_4dBMT
Speed Between Antennas (m/min)                   -0.06058                     -0.05491                     -0.05406                      0.05292
                                                   0.2011                       0.2548                       0.2540                       0.2626
                                                      447                          432                          447                          450
```

```
                                       Fishway Navigation Speed

----------------------------------------------------------------- Site=STP ------------------------------------------------------------

                                   Spearman Correlation Coefficients
                                      Prob > |r| under H0: Rho=0
                                       Number of Observations

Navig_Speed                          Log_PPT                      StampDailyDischargeEst       Root4_PPT_2dBMT              STP_Temp_4dBMWT
Speed Through Antennas (m/min)                    0.13486                      0.11874                      0.11502                     -0.10541
                                                   0.0228                       0.0452                       0.0651                       0.0756
                                                      285                          285                          258                          285

Navig_Speed                          Root4_PPT                    Log_PPT_2dBMT                PMD_Temp_4dBMWT              Root4_PPT_3dBMT
Speed Through Antennas (m/min)                    0.10201                      0.09445                     -0.08371                      0.08255
                                                   0.1706                       0.1116                       0.1609                       0.1661
                                                      182                          285                          282                          283

Navig_Speed                          STP_Temp_3dBMWT              Root4_PPT_4dBMT              STP_Level_4dBMA              STP_WaterLevel
Speed Through Antennas (m/min)                   -0.08072                      0.07864                      0.07350                      0.06977
                                                   0.1742                       0.1856                       0.2161                       0.2404
                                                      285                          285                          285                          285

Navig_Speed                          PMD_Temp_3dBMWT              STP_Temp_7dBMWT              STP_Level_3dBMA              STP_Level_2dBMA
Speed Through Antennas (m/min)                   -0.06897                     -0.06893                      0.06691                      0.06379
                                                   0.2483                       0.2461                       0.2602                       0.2870
                                                      282                          285                          285                          285

Navig_Speed                          STP_Level_7dBMA              PMD_Temp_7dBMWT              Log_PPT_4dBMT                Log_PPT_7dBMT
Speed Through Antennas (m/min)                    0.06293                     -0.05763                      0.05665                      0.05126
                                                   0.2897                       0.3349                       0.3406                       0.3887
                                                      285                          282                          285                          285
```

Table 20. Top Spearman rank correlation coefficients for Sproat River *fishway transit speed* (meters/minute) (top) and Stamp River fishway *navigation speed* (bottom) for individual tags as a function of daily mean values of environmental variates (Stamp/Somass River multi-day backward-averaged water level and temperature, Sproat Lake and Sproat River water levels, precipitation, barometric air pressure, and air temperature). Significant ($P < 0.05$) independent environmental variates highlighted in yellow for each tag indicator type; weakly significant ($P < 0.10$) correlations in orange.

```
                         Stamp Fishway Navigation Speed

                            The GLMSELECT Procedure

                             LAR Selection Summary

             Effect                          Number        Model
      Step   Entered                       Effects In    R-Square          AICC

         0   Intercept                              1      0.0000      431.9633
---------------------------------------------------------------------------------
         1   StampDailyDischargeE                   2      0.0184      428.7165*
         2   STP_Temp_7dBMWT                        3      0.0188      430.6441

                         * Optimal Value Of Criterion

                             Analysis of Variance

                                     Sum of          Mean
Source                   DF         Squares        Square    F Value    Pr > F

Model                     2         8.86389       4.43195       2.71    0.0685
Error                   282       461.71591       1.63729
Corrected Total         284       470.57980

                    Root MSE                 1.27957
                    Dependent Mean           1.49862
                    R-Square                  0.0188
                    Adj R-Sq                  0.0119
                    AIC                    430.50127
                    AICC                   430.64413
                    SBC                    154.45874

                             Parameter Estimates

               Parameter                DF         Estimate

               Intercept                 1        -0.479459
               StampDailyDischargeE      1         0.028565
               STP_Temp_7dBMWT           1         0.047638
```

Table 21. Stepwise model selection based on r² improvements retained same-day Stamp River daily discharge and Stamp River 7-day moving average water temperature indicator (STP_Temp_7dBMWT) as significant predictors of overall tag speed (meters/minute, log-transfoTable 21rmed) between antennas in the Stamp fishway. Optimum Akaike Information Criterion (AICC) was found for the Stamp River daily discharge indicator.

```
                         Stamp Fishway Navigation Speed

                                Selected Model

                             Analysis of Variance

                                     Sum of          Mean
Source                   DF         Squares        Square    F Value    Pr > F

Model                     1         8.65353       8.65353       5.30    0.0220
Error                   283       461.92627       1.63225
Corrected Total         284       470.57980

                    Root MSE                 1.27759
                    Dependent Mean           1.49862
                    R-Square                  0.0184
                    Adj R-Sq                  0.0149
                    AIC                    428.63109
                    AICC                   428.71650
                    SBC                    148.93607

                             Parameter Estimates

               Parameter                DF         Estimate

               Intercept                 1         0.657474
               StampDailyDischargeE      1         0.021243
```

Table 22. LAR model selection retained only daily mean Stamp discharge as the significant predictor for (log-transformed) tag transit speed (meters per minute) through Stamp fishway.

```
                          Sproat Fishway Transit Speed

                            The GLMSELECT Procedure

                             LAR Selection Summary

                Effect                         Number       Model
        Step    Entered                    Effects In    R-Square           AICC

           0    Intercept                           1      0.0000       490.0885
      ---------------------------------------------------------------------------
           1    PMD_Temp_3dBMWT                     2      0.0232       482.0573*
           2    SPR_Temp_BCCF                       3      0.0259       482.9143
           3    STP_Level_7dBMA                     4      0.0281       483.9852
           4    SPR_Flow_Lag0_7dBMF                 5      0.0344       483.2536
           5    SPR_WL_Lag0_3dBMWL                  6      0.0409       482.4138
           6    Baro_2dBMA                          7      0.0445       482.8800

                          * Optimal Value Of Criterion

                              Analysis of Variance

                                        Sum of          Mean
  Source                     DF        Squares        Square    F Value    Pr > F

  Model                       6       21.80061       3.63343       3.27    0.0037
  Error                     422      468.22839       1.10955
  Corrected Total           428      490.02900


                    Root MSE                 1.05335
                    Dependent Mean           0.57575
                    R-Square                  0.0445
                    Adj R-Sq                  0.0309
                    AIC                    482.53719
                    AICC                   482.88005
                    SBC                     79.96739

                              Parameter Estimates

               Parameter                DF         Estimate

               Intercept                 1      -432.882437
               PMD_Temp_3dBMWT           1        -0.475048
               SPR_Temp_BCCF             1         0.176925
               STP_Level_7dBMA           1        -0.363214
               SPR_Flow_Lag0_7dBMF       1        -0.179713
               SPR_WL_Lag0_3dBMWL        1         7.383353
               Baro_2dBMA                1        -0.454771
```

Table 23. Stepwise model selection based on r^2 improvements retained Somass River 3-day moving average water temperature indicator (PMD_Temp_3dBMWT), same-day Sproat River water temperature (SPR_Temp_BCCF), Stamp and Sproat River mean water level for the past 7 days (STP_Level_7dBMA and SPR_Flow_Lag0_7dBMF), Sproat Lake water levels for the past 3 days (SPR_WL_Lag0_3dBMWL), and barometric pressure over the past two days (Baro_2dBMA) as significant predictors of tag transit speed (meters/minute, log-transformed) between antennas in the Sproat fishway. Optimum Akaike Informmation Criterion (AICC) was found for the Somass River 3-day water temperature indicator.

```
                          Sproat Fishway Transit Speed

                                 Selected Model

                              Analysis of Variance

                                        Sum of          Mean
  Source                     DF        Squares        Square    F Value    Pr > F

  Model                       1       11.35679      11.35679      10.13    0.0016
  Error                     427      478.67222       1.12101
  Corrected Total           428      490.02900


                    Root MSE                 1.05878
                    Dependent Mean           0.57575
                    R-Square                  0.0232
                    Adj R-Sq                  0.0209
                    AIC                    482.00087
                    AICC                   482.05734
                    SBC                     59.12378

                              Parameter Estimates

               Parameter                DF         Estimate

               Intercept                 1         3.058281
               PMD_Temp_3dBMWT           1        -0.135255
```

Table 24. LAR model selection retained only Somass River 3-day moving average water temperature indicator (PMD_Temp_3dBMWT) as the significant predictor of tag transit speed (meters per minute) between antennas in Sproat fishway.

	Days					Speed km/d				
	N	Min	Mean	Max	Std	N	Min	Mean	Max	Std
Location										
GCL	91	3.00	5.41	12.00	1.95	91	1.95	4.95	8.25	1.62
SPR	313	1.00	3.62	12.00	1.58	313	0.49	1.88	7.15	0.83
STP	122	1.00	3.40	10.00	1.61	122	1.04	3.44	7.40	1.27

Table 25. Statistics for travel time (days) and speed (km/d) to tag detection locations for fish tagged at Papermill Dam.

	Days					Speed km/d				
	N	Min	Mean	Max	Std	N	Min	Mean	Max	Std
Location										
STP	144	4.00	15.72	35.00	7.49	144	1.43	4.01	12.55	2.04
GCL	131	6.00	17.16	35.00	6.95	131	1.74	4.36	10.62	1.80
SPR	240	3.00	13.11	33.00	6.95	240	1.39	4.60	15.28	2.57

Table 26. Statistics for travel time (days) and speed (km/d) to tag detection locations for fish tagged in Alberni Inlet.

```
---------------------------- Tagging Location=PMD Stock=STP ----------------------------------

                               The GLMSELECT Procedure

                                LAR Selection Summary

       Effect                Number     Adjusted
Step   Entered             Effects In   R-Square        AICC            SBC      F Value

   0   Intercept                    1     0.0000     661.5980       540.3011        0.00
----------------------------------------------------------------------------------------
   1   PMD_Tmax_BCCF                2     0.0316*    658.7744*      540.1791*       4.94

                            * Optimal Value Of Criterion


                                Analysis of Variance

                                            Sum of          Mean
         Source                  DF        Squares        Square    F Value

         Model                    1      389.06544     389.06544       4.94
         Error                  120     9442.38485      78.68654
         Corrected Total        121     9831.45030


                      Root MSE                8.87054
                      Dependent Mean          2.90141
                      R-Square                 0.0396
                      Adj R-Sq                 0.0316
                      AIC                   658.57102
                      AICC                  658.77441
                      SBC                   540.17907
```

Table 27. Stepwise least-angular-regression (LAR) model retained only Somass daily maximum water temperature as a significant predictor of tag travel rate (km/d) to the Stamp fishway for river-tagged fish (r^2 = .03, n = 122).

```
---------------------------- Tagging Location=PMD Stock=SPR ------------------------------------

                               The GLMSELECT Procedure

                                LAR Selection Summary

       Effect                    Number     Adjusted
Step   Entered                 Effects In   R-Square        AICC            SBC      F Value

   0   Intercept                        1     0.0000    1428.5165      1109.2502        0.00
--------------------------------------------------------------------------------------------
   1   PMD_Temp_Lag3_1dBMWT             2     0.0277    1420.5311      1104.9982       10.12
   2   Baro_7dBMA                       3     0.1220    1388.8302      1077.0180       35.26
   3   Date                             4     0.1418*   1382.5679*     1074.4632*       8.33

                            * Optimal Value Of Criterion


                                Analysis of Variance

                                            Sum of          Mean
         Source                  DF        Squares        Square    F Value

         Model                    3     1496.31704     498.77235      18.62
         Error                  317     8490.98359      26.78544
         Corrected Total        320     9987.30063


                      Root MSE                5.17546
                      Dependent Mean          1.58668
                      R-Square                 0.1498
                      Adj R-Sq                 0.1418
                      AIC                  1382.37740
                      AICC                 1382.56788
                      SBC                  1074.46316
```

Table 28. Stepwise least-angular-regression (LAR) model retained lagged Somass daily mean water temperature, barometric pressure, and date as significant predictors of tag travel rate (km/d) to the Sproat fishway for river-tagged fish (r^2 = .14, N=321).

```
-------------------------- Tagging Location=Argent 1 Stock=STP --------------------------------

                                  The GLMSELECT Procedure

                                   LAR Selection Summary

          Effect                  Number    Adjusted
 Step     Entered              Effects In   R-Square            AICC            SBC      F Value

    0     Intercept                     1     0.0000        866.1096       735.8910         0.00
-----------------------------------------------------------------------------------------------
    1     PMD_Temp_7dBMWT               2     0.1098        851.9498       724.5112        17.04
    2     Date                          3     0.1945*       839.9700*      715.2781*       14.55

                               * Optimal Value Of Criterion


                                   Analysis of Variance

                                             Sum of           Mean
            Source                 DF       Squares         Square    F Value

            Model                   2    7185.74601     3592.87301      16.69
            Error                 128         27548      215.21975
            Corrected Total       130         34734

                         Root MSE                14.67037
                         Dependent Mean           3.58603
                         R-Square                  0.2069
                         Adj R-Sq                  0.1945
                         AIC                    839.65252
                         AICC                   839.96998
                         SBC                    715.27812
```

Table 29. Stepwise least-angular-regression (LAR) model retained the 7-day moving average Somass mean water temperature indicator and the date as significant predictors of tag travel rate (km/d) to the Stamp fishway for ocean-tagged fish (r^2 = .19, n = 131).

```
--------------------------- Tagging Location=Argent 1 Stock=SPR ----------------------------------

                                  The GLMSELECT Procedure

                                   LAR Selection Summary

          Effect                  Number    Adjusted
 Step     Entered              Effects In   R-Square            AICC            SBC      F Value

    0     Intercept                     1     0.0000       1566.1533      1345.5012         0.00
-----------------------------------------------------------------------------------------------
    1     PMD_Temp_3dBMWT               2     0.1006       1543.6547      1326.3500        25.73
    2     SPR_Temp_3dBMWT               3     0.1802*      1524.1641*     1310.1878*       22.34

                               * Optimal Value Of Criterion


                                   Analysis of Variance

                                             Sum of           Mean
            Source                 DF       Squares         Square    F Value

            Model                   2         17424     8712.19548      25.28
            Error                 219         75464      344.58586
            Corrected Total       221         92889

                         Root MSE                18.56302
                         Dependent Mean           4.08583
                         R-Square                  0.1876
                         Adj R-Sq                  0.1802
                         AIC                   1523.97975
                         AICC                  1524.16408
                         SBC                   1310.18779
```

Table 30. Stepwise least-angular-regression (LAR) model retained the 3-day moving average Somass mean water temperature indicator and the 3-day moving average Sproat River mean water temperature indicator as significant predictors of tag travel rate (km/d) to the Sproat fishway for ocean-tagged fish (r^2 = .18, n = 222).

```
                         STP LAR MULTIVARIATE REGRESSION - for Argent 1

------------------------- Tagging Location=Argent 1 Stock=STP ---------------------------------

                                   The GLMSELECT Procedure

                                    LAR Selection Summary

           Effect                   Number    Adjusted
   Step    Entered               Effects In   R-Square          AICC         SBC     F Value

      0    Intercept                      1     0.0000       31.5013     19.1807        0.00
------------------------------------------------------------------------------------------
      1    PMD_Temp_7dBMWT                2     0.7434       24.9864      9.1453       21.28
      2    STP_Level_7dBMA                3     0.9184       23.6937*     0.5987       13.87
      3    Baro_4dBMA                     4     0.9273*      39.6503     -0.0319*       1.61

                               * Optimal Value Of Criterion

                                    Analysis of Variance

                                             Sum of         Mean
           Source                  DF       Squares       Square    F Value

           Model                    2      63.88334     31.94167      40.40
           Error                    5       3.95307      0.79061
           Corrected Total          7      67.83641


                      Root MSE                   0.88916
                      Dependent Mean             3.58603
                      R-Square                    0.9417
                      Adj R-Sq                    0.9184
                      AIC                       10.36040
                      AICC                      23.69374
                      SBC                        0.59873

                                   Parameter Estimates

                     Parameter           DF         Estimate

                     Intercept            1        13.259216
                     PMD_Temp_7dBMWT      1        -0.631262
                     STP_Level_7dBMA      1         1.745291
```

Table 31. Stepwise least-angular-regression (LAR) for weekly summary data retained the 7-day moving average Somass mean water temperature indicator (74% of variance) and the 7-day moving average mean Stamp River water level (17% of variance) as significant predictors of tag travel rate (km/d) to the Stamp fishway for ocean-tagged fish (r^2 = .92, n = 8). A barometric pressure variate which accounted for less than 1% of model variance was dropped as it failed to meet AICC criteria.

```
                         SPR LAR MULTIVARIATE REGRESSION - for Argent 1

------------------------------ Tagging Location=Argent 1 Stock=SPR ------------------------------------

                                   The GLMSELECT Procedure

                                    LAR Selection Summary

          Effect                      Number    Adjusted
 Step     Entered                   Effects In  R-Square          AICC          SBC    F Value

    0     Intercept                          1    0.0000       34.1727      21.9645       0.00
-----------------------------------------------------------------------------------------------
    1     PMD_Temp_3dBMWT                    2    0.9625       23.1334*      2.7169     129.33
    2     BARO                               3    0.9698*      50.1102       1.4855*      1.97

                                * Optimal Value Of Criterion

                                    Analysis of Variance

                                             Sum of          Mean
               Source               DF      Squares        Square    F Value

               Model                 1    167.90878     167.90878     129.33
               Error                 4      5.19306       1.29826
               Corrected Total       5    173.10183

                           Root MSE                1.13941
                           Dependent Mean          4.10156
                           R-Square                 0.9700
                           Adj R-Sq                 0.9625
                           AIC                    11.13338
                           AICC                   23.13338
                           SBC                     2.71690

                                    Parameter Estimates

                        Parameter              DF        Estimate

                         Intercept              1       20.633564
                        PMD_Temp_3dBMWT         1       -0.917370
```

Table 32. Stepwise least-angular-regression (LAR) for weekly summary data retained only the 3-day moving average Somass mean water temperature indicator (96% of model variance) as a significant predictor of tag travel rate (km/d) to the Sproat fishway for ocean-tagged fish ($r^2 = .96$, $n = 8$). Barometric pressure, which would have accounted for less than 1% of model variance was dropped as it failed to meet AICC criteria.

Variate	Range	Classification
Travel Rate (km/d)	0 – 2	Slow
	2.01 – 4	Medium
	> 4	High
Somass Water Temperature (°C)	<=18	Cool
	18.01 - 20	Warm
	20.01 - 22	Hot
	> 22	Very Hot
Sproat Water Temperature (°C)	<=18	Cool
	18.01 - 20	Warm
	20.01 - 22	Hot
	> 22	Very Hot
Stamp Water Temperature (°C)	<= 19	Cool
	> 19	Warm
Sproat Water Level (m)	<=59.8	Low
	> 59.8	Hign
Stamp Water Level (m)	<=1	Low
	> 1	High
Barometric Pressure (mm)	<=0.84	Low
	> 0.84	High
Precipitation (mm)	<=0.001	None
	0.0011 - 1	Low
	> 1.0	High

Table 33. Categorical factor analysis bins for Sockeye migration response variate (Travel Rate (km/d)) and environmental variates.

```
------------------------- Tagging Location=Ocean Stock=SPR ------------------------

                          The CORRESP Procedure

                 Greenacre Adjusted Inertia Decomposition

 Principal     Adjusted                   Cumulative
   Inertia      Inertia      Percent         Percent       11   22   33   44   55
                                                       ----+----+----+----+----+---
   0.60669      0.53976        55.08           55.08   *************************
   0.24589      0.15606        15.92           71.00   *******
   0.22364      0.13505        13.78           84.78   ******
   0.14940      0.06960         7.10           91.89   ***
   0.12890      0.05329         5.44           97.32   **
   0.08785      0.02424         2.47           99.80   *
   0.04160      0.00200         0.20          100.00

     Total      0.98000       100.00
```

Table 34. Multiple correspondence categorical analysis results for ocean-tagged Sproat-bound fish travel rates (km/d) categories in association with environmental variables in the Somass/Sproat waterbodies. Dimension 1 defined by "cool, wet" conditions corresponding with high travel rates (>6 km/d), and "warm, dry" conditions corresponding with low travel rates (0-3 km/d) contributes to 55% of the principal inertia.

```
------------------------- Tagging Location=Ocean Stock=GCL ------------------------

                          The CORRESP Procedure

                 Greenacre Adjusted Inertia Decomposition

 Principal     Adjusted                   Cumulative
   Inertia      Inertia      Percent         Percent        7   14   21   28   35
                                                       ----+----+----+----+----+---
   0.37553      0.28661        33.87           33.87   ************************
   0.31583      0.22504        26.59           60.47   *******************
   0.20798      0.12059        14.25           74.72   **********
   0.17241      0.08896        10.51           85.23   ********
   0.13538      0.05833         6.89           92.12   *****
   0.10504      0.03569         4.22           96.34   ***
   0.07110      0.01439         1.70           98.04   *
   0.06527      0.01136         1.34           99.38   *
   0.05147      0.00522         0.62          100.00

     Total      0.84620       100.00
```

Table 35. Multiple correspondence categorical analysis results for ocean-tagged GCL-bound fish travel rates (km/d) categories in association with environmental variables in the Somass/Stamp waterbodies. Dimension 1 defined by "cool, wet" conditions corresponding with high travel rates (>6 km/d), and "warm, dry" conditions corresponding with low travel rates (0-3 km/d) contributes to 34% of the principal inertia.

```
------------------------ Tagging Location=River Stock=SPR ---------------------------

                           The CORRESP Procedure

                  Greenacre Adjusted Inertia Decomposition

 Principal     Adjusted                  Cumulative
   Inertia      Inertia     Percent        Percent      7    14    21    28    35
                                                    ----+----+----+----+----+---
   0.44390      0.35941       35.61          35.61  *************************
   0.34465      0.25450       25.21          60.82  ******************
   0.25788      0.16760       16.60          77.43  ************
   0.18409      0.09914        9.82          87.25  *******
   0.16632      0.08374        8.30          95.55  ******
   0.07962      0.01921        1.90          97.45  *
   0.07500      0.01654        1.64          99.09  *
   0.05713      0.00754        0.75          99.84  *
   0.04023      0.00166        0.16         100.00

     Total      1.00934      100.00
```

Table 36. Multiple correspondence categorical analysis results for river-tagged Sproat-bound fish travel rates (km/d) categories in association with environmental variables in the Somass/Sproat waterbodies. Dimension 1, defined by "cool, wet" conditions corresponding with high travel rates (>6 km/d), and "warm, dry" conditions corresponding with low travel rates (0-3 km/d), contributed to 35% of the principal inertia.

```
------------------------------ Tagging Location=River Stock=GCL ----------------------------------

                               The CORRESP Procedure

                       Inertia and Chi-Square Decomposition

                     Greenacre Adjusted Inertia Decomposition

 Principal     Adjusted                  Cumulative
   Inertia      Inertia     Percent        Percent      7    14    21    28    35
                                                    ----+----+----+----+----+---
   0.36040      0.27082       36.51          36.51  **************************
   0.21064      0.12302       16.59          53.10  ************
   0.19673      0.11029       14.88          67.99  ***********
   0.16980      0.08672       11.69          79.68  ********
   0.13511      0.05812        7.84          87.52  ******
   0.12433      0.04979        6.71          94.23  *****
   0.11498      0.04281        5.77         100.00  ****

     Total      0.74167      100.00
```

Table 37. Multiple correspondence categorical analysis results for ocean-tagged GCL-bound fish travel rates (km/d) categories in association with environmental variables in the Somass/Stamp waterbodies. Dimension 1 contributed to 37% of the principal inertia.

```
------- Tagging Location=Ocean Stock=GCL ----------

                The FREQ Procedure

      Table of PMD_Temp_Cat by FishSpeedCat

    PMD_Temp_Cat(Somass Temp C (3d Avg))
              FishSpeedCat(Mig Rate Category (km/d))

    Frequency|
    Row Pct  |
    Col Pct  |0-2     |2-4     |4+      |  Total
    ---------+--------+--------+--------+
    16-17    |      0 |     10 |      9 |     19
             |   0.00 |  52.63 |  47.37 |
             |   0.00 |  15.15 |  18.75 |
    ---------+--------+--------+--------+
    17-18    |      1 |     10 |      8 |     19
             |   5.26 |  52.63 |  42.11 |
             |   5.88 |  15.15 |  16.67 |
    ---------+--------+--------+--------+
    18-19    |      5 |     28 |     29 |     62
             |   8.06 |  45.16 |  46.77 |
             |  29.41 |  42.42 |  60.42 |
    ---------+--------+--------+--------+
    19-20    |     10 |     16 |      2 |     28
             |  35.71 |  57.14 |   7.14 |
             |  58.82 |  24.24 |   4.17 |
    ---------+--------+--------+--------+
    20-21    |      1 |      2 |      0 |      3
             |  33.33 |  66.67 |   0.00 |
             |   5.88 |   3.03 |   0.00 |
    ---------+--------+--------+--------+
    Total          17       66       48      131

                  Somers' D C|R
          ------------------------------------
          Somers' D C|R               -0.2883
          ASE                          0.0622
          95% Lower Conf Limit        -0.4102
          95% Upper Conf Limit        -0.1663

            Test of H0: Somers' D C|R = 0

          ASE under H0                 0.0638
          Z                           -4.5149
          One-sided Pr <  Z            <.0001
          Two-sided Pr > |Z|           <.0001
```

Table 38. Two-way frequency analysis for ocean-tagged GCL-bound Sockeye migration rate categories (km/d, in columns) versus Somass water temperature categories (°C, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
------- Tagging Location=Ocean Stock=GCL ----------

                The FREQ Procedure

     Table of STP_Temp_Cat by FishSpeedCat

STP_Temp_Cat(Stamp Temp C (3d Avg))
          FishSpeedCat(Mig Rate Category (km/d))

Frequency|
Row Pct  |
Col Pct  |0-2     |2-4     |4+      |  Total
---------+--------+--------+--------+
15-16    |      0 |      3 |      3 |      6
         |   0.00 |  50.00 |  50.00 |
         |   0.00 |   4.55 |   6.25 |
---------+--------+--------+--------+
16-17    |      0 |     10 |     10 |     20
         |   0.00 |  50.00 |  50.00 |
         |   0.00 |  15.15 |  20.83 |
---------+--------+--------+--------+
17-18    |      5 |     28 |     24 |     57
         |   8.77 |  49.12 |  42.11 |
         |  29.41 |  42.42 |  50.00 |
---------+--------+--------+--------+
18-19    |      7 |     19 |     11 |     37
         |  18.92 |  51.35 |  29.73 |
         |  41.18 |  28.79 |  22.92 |
---------+--------+--------+--------+
19-20    |      5 |      6 |      0 |     11
         |  45.45 |  54.55 |   0.00 |
         |  29.41 |   9.09 |   0.00 |
---------+--------+--------+--------+
Total          17       66       48      131

             Somers' D C|R
     ------------------------------------
     Somers' D C|R              -0.2646
     ASE                         0.0634
     95% Lower Conf Limit       -0.3889
     95% Upper Conf Limit       -0.1404

      Test of H0: Somers' D C|R = 0

     ASE under H0                0.0654
     Z                          -4.0472
     One-sided Pr <  Z           <.0001
     Two-sided Pr > |Z|          <.0001
```

Table 39. Two-way frequency analysis for ocean-tagged GCL-bound Sockeye migration rate categories (km/d, in columns) versus Stamp water temperature categories (°C, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
------ Tagging Location=Ocean Stock=GCL ----------

                The FREQ Procedure

      Table of SPR_Temp_Cat by FishSpeedCat

   SPR_Temp_Cat(Sproat Temp C (3d Avg))
             FishSpeedCat(Mig Rate Category (km/d))

   Frequency|
   Row Pct  |
   Col Pct  |0-2     |2-4     |4+      |  Total
   ---------+--------+--------+--------+
   18-19    |      0 |     11 |     11 |     22
            |   0.00 |  50.00 |  50.00 |
            |   0.00 |  16.67 |  22.92 |
   ---------+--------+--------+--------+
   19-20    |      0 |      6 |      7 |     13
            |   0.00 |  46.15 |  53.85 |
            |   0.00 |   9.09 |  14.58 |
   ---------+--------+--------+--------+
   20-21    |      1 |     16 |     20 |     37
            |   2.70 |  43.24 |  54.05 |
            |   5.88 |  24.24 |  41.67 |
   ---------+--------+--------+--------+
   >21      |     16 |     33 |     10 |     59
            |  27.12 |  55.93 |  16.95 |
            |  94.12 |  50.00 |  20.83 |
   ---------+--------+--------+--------+
   Total          17       66       48      131

               Somers' D C|R
       ----------------------------------
       Somers' D C|R              -0.3412
       ASE                         0.0638
       95% Lower Conf Limit       -0.4662
       95% Upper Conf Limit       -0.2163

        Test of H0: Somers' D C|R = 0

       ASE under H0                0.0616
       Z                          -5.5383
       One-sided Pr <  Z           <.0001
       Two-sided Pr > |Z|          <.0001
```

Table 40. Two-way frequency analysis for ocean-tagged GCL-bound Sockeye migration rate categories (km/d, in columns) versus Sproat water temperature categories (°C, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
-------- Tagging Location=Ocean Stock=GCL ----------

                The FREQ Procedure

    Table of STP_Water_Level_Cat by FishSpeedCat

   STP_Water_Level_Cat(Stamp Water Level)
             FishSpeedCat(Mig Rate Category (km/d))

   Frequency|
   Row Pct  |
   Col Pct  |0-2     |2-4     |4+      |  Total
   ---------+--------+--------+--------+
   0.74-0.81|      2 |      2 |      0 |      4
            |  50.00 |  50.00 |   0.00 |
            |  11.76 |   3.03 |   0.00 |
   ---------+--------+--------+--------+
   0.81-0.90|     12 |     36 |     19 |     67
            |  17.91 |  53.73 |  28.36 |
            |  70.59 |  54.55 |  39.58 |
   ---------+--------+--------+--------+
   0.95-1.20|      3 |     28 |     29 |     60
            |   5.00 |  46.67 |  48.33 |
            |  17.65 |  42.42 |  60.42 |
   ---------+--------+--------+--------+
   Total          17       66       48      131

                 Somers' D C|R
        ----------------------------------
        Somers' D C|R               0.2917
        ASE                         0.0811
        95% Lower Conf Limit        0.1328
        95% Upper Conf Limit        0.4507

          Test of H0: Somers' D C|R = 0

        ASE under H0                0.0830
        Z                           3.5152
        One-sided Pr >  Z           0.0002
        Two-sided Pr > |Z|          0.0004
```

Table 41. Two-way frequency analysis for ocean-tagged GCL-bound Sockeye migration rate categories (km/d, in columns) versus Stamp water level categories (meters, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
--------- Tagging Location=Ocean Stock=GCL ----------

                 The FREQ Procedure

      Table of SPR_Water_Level_Cat by FishSpeedCat

     SPR_Water_Level_Cat(Sproat Lake Level)
                 FishSpeedCat(Mig Rate Category (km/d))

     Frequency|
     Row Pct  |
     Col Pct  |0-2     |2-4     |4+      |  Total
     ---------+--------+--------+--------+
     59.5-59.6|      5 |      8 |      0 |     13
              |  38.46 |  61.54 |   0.00 |
              |  29.41 |  12.12 |   0.00 |
     ---------+--------+--------+--------+
     59.6-59.7|      9 |     16 |      4 |     29
              |  31.03 |  55.17 |  13.79 |
              |  52.94 |  24.24 |   8.33 |
     ---------+--------+--------+--------+
     59.7-59.8|      3 |     31 |     33 |     67
              |   4.48 |  46.27 |  49.25 |
              |  17.65 |  46.97 |  68.75 |
     ---------+--------+--------+--------+
     59.8-60.0|      0 |     11 |     11 |     22
              |   0.00 |  50.00 |  50.00 |
              |   0.00 |  16.67 |  22.92 |
     ---------+--------+--------+--------+
     Total          17       66       48      131

                    Somers' D C|R
         ------------------------------------
         Somers' D C|R                 0.3779
         ASE                           0.0591
         95% Lower Conf Limit          0.2620
         95% Upper Conf Limit          0.4938

           Test of H0: Somers' D C|R = 0

         ASE under H0                  0.0626
         Z                             6.0388
         One-sided Pr >  Z             <.0001
         Two-sided Pr > |Z|            <.0001
```

Table 42. Two-way frequency analysis for ocean-tagged GCL-bound Sockeye migration rate categories (km/d, in columns) versus Sproat water level categories (meters, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
--------- Tagging Location=Ocean Stock=GCL ----------

                  The FREQ Procedure

        Table of Ppt_Level_Cat by FishSpeedCat

    Ppt_Level_Cat(Precipitation Level)
              FishSpeedCat(Mig Rate Category (km/d))

    Frequency|
    Row Pct  |
    Col Pct  |0-2     |2-4     |4+      |  Total
    ---------+--------+--------+--------+
    0.None   |     15 |     53 |     36 |    104
             |  14.42 |  50.96 |  34.62 |
             |  88.24 |  80.30 |  75.00 |
    ---------+--------+--------+--------+
    1.Low    |      2 |      2 |      2 |      6
             |  33.33 |  33.33 |  33.33 |
             |  11.76 |   3.03 |   4.17 |
    ---------+--------+--------+--------+
    2.High   |      0 |     11 |     10 |     21
             |   0.00 |  52.38 |  47.62 |
             |   0.00 |  16.67 |  20.83 |
    ---------+--------+--------+--------+
    Total          17       66       48      131

                 Somers' D C|R
          ------------------------------
          Somers' D C|R           0.1380
          ASE                     0.1008
          95% Lower Conf Limit   -0.0595
          95% Upper Conf Limit    0.3356

           Test of H0: Somers' D C|R = 0

          ASE under H0            0.1025
          Z                       1.3467
          One-sided Pr >  Z       0.0890
          Two-sided Pr > |Z|      0.1781
```

Table 43. Two-way frequency analysis for ocean-tagged GCL-bound Sockeye migration rate categories (km/d, in columns) versus precipitation level categories (zero, <1 mm/d and >1 mm/d; in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
--------- Tagging Location=Ocean Stock=GCL ----------

                   The FREQ Procedure

          Table of Baro_Level_Cat by FishSpeedCat

      Baro_Level_Cat(Baro Pressure Level)
                 FishSpeedCat(Mig Rate Category (km/d))

      Frequency|
      Row Pct  |
      Col Pct  |0-2     |2-4     |4+      |  Total
      ---------+--------+--------+--------+
      0.78-0.83|      0 |      1 |      0 |      1
               |   0.00 | 100.00 |   0.00 |
               |   0.00 |   1.52 |   0.00 |
      ---------+--------+--------+--------+
      0.83-0.85|      5 |      3 |      1 |      9
               |  55.56 |  33.33 |  11.11 |
               |  29.41 |   4.55 |   2.08 |
      ---------+--------+--------+--------+
      0.85-0.88|      9 |     37 |     24 |     70
               |  12.86 |  52.86 |  34.29 |
               |  52.94 |  56.06 |  50.00 |
      ---------+--------+--------+--------+
      0.88-0.90|      3 |     25 |     23 |     51
               |   5.88 |  49.02 |  45.10 |
               |  17.65 |  37.88 |  47.92 |
      ---------+--------+--------+--------+
      Total          17       66       48      131

                     Somers' D C|R
        ------------------------------------
        Somers' D C|R                 0.2312
        ASE                           0.0818
        95% Lower Conf Limit          0.0708
        95% Upper Conf Limit          0.3915

          Test of H0: Somers' D C|R = 0

        ASE under H0                  0.0843
        Z                             2.7406
        One-sided Pr >  Z             0.0031
        Two-sided Pr > |Z|            0.0061
```

Table 44. Two-way frequency analysis for ocean-tagged GCL-bound Sockeye migration rate categories (km/d, in columns) versus barometric pressure level categories (mm, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
------- Tagging Location=Ocean Stock=SPR ----------

                The FREQ Procedure

        Table of PMD_Temp_Cat by FishSpeedCat

   PMD_Temp_Cat(Somass Temp C (3d Avg))
            FishSpeedCat(Mig Rate Category (km/d))

   Frequency|
   Row Pct  |
   Col Pct  |0-2     |2-4     |4+      |  Total
   ---------+--------+--------+--------+
   16-17    |      0 |      9 |     30 |     39
            |   0.00 |  23.08 |  76.92 |
            |   0.00 |  11.11 |  26.55 |
   ---------+--------+--------+--------+
   17-18    |      4 |     21 |     33 |     58
            |   6.90 |  36.21 |  56.90 |
            |  12.90 |  25.93 |  29.20 |
   ---------+--------+--------+--------+
   18-19    |     11 |     25 |     42 |     78
            |  14.10 |  32.05 |  53.85 |
            |  35.48 |  30.86 |  37.17 |
   ---------+--------+--------+--------+
   19-20    |     15 |     24 |      8 |     47
            |  31.91 |  51.06 |  17.02 |
            |  48.39 |  29.63 |   7.08 |
   ---------+--------+--------+--------+
   20-21    |      1 |      2 |      0 |      3
            |  33.33 |  66.67 |   0.00 |
            |   3.23 |   2.47 |   0.00 |
   ---------+--------+--------+--------+
   Total          31       81      113      225

                  Somers' D C|R
       ----------------------------------
       Somers' D C|R              -0.3161
       ASE                         0.0437
       95% Lower Conf Limit       -0.4018
       95% Upper Conf Limit       -0.2304

         Test of H0: Somers' D C|R = 0

       ASE under H0                0.0449
       Z                          -7.0387
       One-sided Pr <  Z           <.0001
       Two-sided Pr > |Z|          <.0001
```

Table 45. Two-way frequency analysis for ocean-tagged Sproat-bound Sockeye migration rate categories (km/d, in columns) versus Somass water temperature categories (°C, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
          Table of STP_Temp_Cat by FishSpeedCat

      STP_Temp_Cat(Stamp Temp C (3d Avg))
                FishSpeedCat(Mig Rate Category (km/d))

      Frequency|
      Row Pct  |
      Col Pct  |0-2     |2-4     |4+      |  Total
      ---------+--------+--------+--------+
      15-16    |      0 |      2 |     11 |     13
               |   0.00 |  15.38 |  84.62 |
               |   0.00 |   2.47 |   9.73 |
      ---------+--------+--------+--------+
      16-17    |      1 |     15 |     40 |     56
               |   1.79 |  26.79 |  71.43 |
               |   3.23 |  18.52 |  35.40 |
      ---------+--------+--------+--------+
      17-18    |      9 |     35 |     45 |     89
               |  10.11 |  39.33 |  50.56 |
               |  29.03 |  43.21 |  39.82 |
      ---------+--------+--------+--------+
      18-19    |     18 |     15 |     17 |     50
               |  36.00 |  30.00 |  34.00 |
               |  58.06 |  18.52 |  15.04 |
      ---------+--------+--------+--------+
      19-20    |      3 |     14 |      0 |     17
               |  17.65 |  82.35 |   0.00 |
               |   9.68 |  17.28 |   0.00 |
      ---------+--------+--------+--------+
      Total          31       81      113      225

                   Somers' D C|R
          --------------------------------
          Somers' D C|R            -0.3431
          ASE                       0.0416
          95% Lower Conf Limit     -0.4246
          95% Upper Conf Limit     -0.2616

            Test of H0: Somers' D C|R = 0

          ASE under H0              0.0433
          Z                        -7.9291
          One-sided Pr <  Z         <.0001
          Two-sided Pr > |Z|        <.0001
```

Table 46. Two-way frequency analysis for ocean-tagged Sproat-bound Sockeye migration rate categories (km/d, in columns) versus Stamp water temperature categories (°C, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
------- Tagging Location=Ocean Stock=SPR ---------

            The FREQ Procedure

   Table of SPR_Temp_Cat by FishSpeedCat

SPR_Temp_Cat(Sproat Temp C (3d Avg))
          FishSpeedCat(Mig Rate Category (km/d))

Frequency|
Row Pct  |
Col Pct  |0-2     |2-4     |4+      |  Total
---------+--------+--------+--------+
18-19    |      0 |     12 |     39 |     51
         |   0.00 |  23.53 |  76.47 |
         |   0.00 |  14.81 |  34.51 |
---------+--------+--------+--------+
19-20    |      2 |      7 |     19 |     28
         |   7.14 |  25.00 |  67.86 |
         |   6.45 |   8.64 |  16.81 |
---------+--------+--------+--------+
20-21    |      6 |     18 |     25 |     49
         |  12.24 |  36.73 |  51.02 |
         |  19.35 |  22.22 |  22.12 |
---------+--------+--------+--------+
>21      |     23 |     44 |     30 |     97
         |  23.71 |  45.36 |  30.93 |
         |  74.19 |  54.32 |  26.55 |
---------+--------+--------+--------+
Total          31       81      113      225

              Somers' D C|R
    --------------------------------
    Somers' D C|R            -0.3275
    ASE                       0.0468
    95% Lower Conf Limit     -0.4192
    95% Upper Conf Limit     -0.2359

     Test of H0: Somers' D C|R = 0

    ASE under H0              0.0465
    Z                        -7.0472
    One-sided Pr <  Z         <.0001
    Two-sided Pr > |Z|        <.0001
```

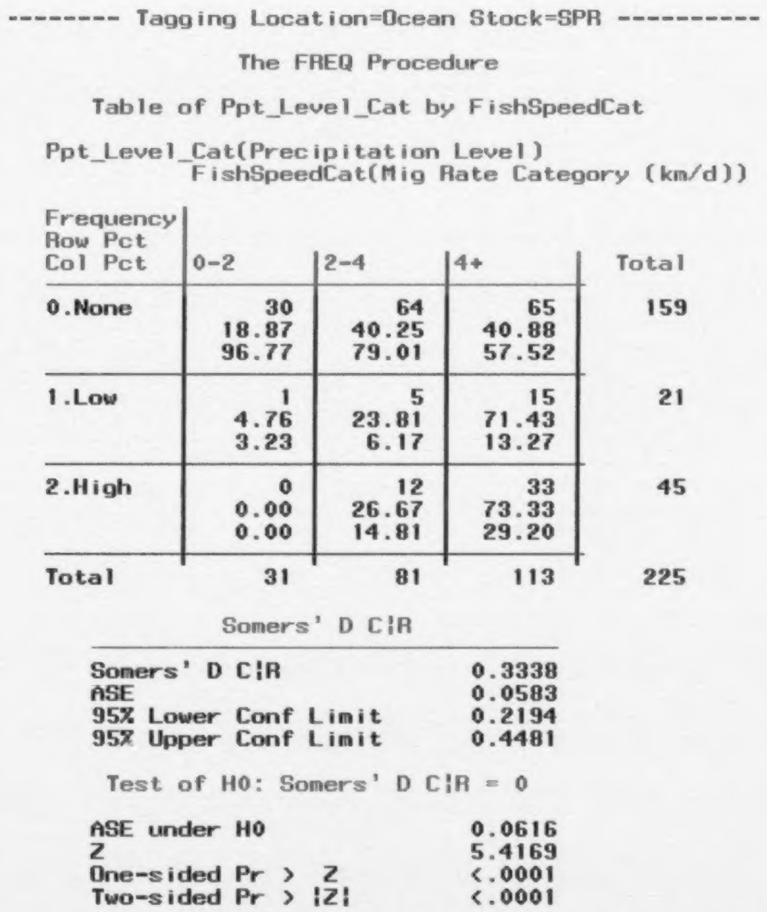
Table 47. Two-way frequency analysis for ocean-tagged Sproat-bound Sockeye migration rate categories (km/d, in columns) versus Sproat water temperature categories (°C, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
--------- Tagging Location=Ocean Stock=SPR ----------

       Table of STP_Water_Level_Cat by FishSpeedCat

     STP_Water_Level_Cat(Stamp Water Level)
                FishSpeedCat(Mig Rate Category (km/d))

     Frequency |
     Row Pct   |
     Col Pct   |0-2     |2-4     |4+      |  Total
     ----------+--------+--------+--------+
     0.81-0.90 |     23 |     43 |     62 |    128
               |  17.97 |  33.59 |  48.44 |
               |  74.19 |  53.09 |  54.87 |
     ----------+--------+--------+--------+
     0.95-1.20 |      8 |     38 |     51 |     97
               |   8.25 |  39.18 |  52.58 |
               |  25.81 |  46.91 |  45.13 |
     ----------+--------+--------+--------+
     Total           31       81      113      225

                 Somers' D C|R
           ----------------------------------------
           Somers' D C|R                0.0841
           ASE                          0.0693
           95% Lower Conf Limit        -0.0518
           95% Upper Conf Limit         0.2200

             Test of H0: Somers' D C|R = 0

           ASE under H0                 0.0694
           Z                            1.2123
           One-sided Pr >  Z            0.1127
           Two-sided Pr > |Z|           0.2254
```

Table 48. Two-way frequency analysis for ocean-tagged Sproat-bound Sockeye migration rate categories (km/d, in columns) versus Stamp water level categories (m, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
-------- Tagging Location=Ocean Stock=SPR ---------

                 The FREQ Procedure

       Table of SPR_Water_Level_Cat by FishSpeedCat

      SPR_Water_Level_Cat(Sproat Lake Level)
                 FishSpeedCat(Mig Rate Category (km/d))

      Frequency|
      Row Pct  |
      Col Pct  |0-2     |2-4     |4+      |  Total
      ---------+--------+--------+--------+
      59.5-59.6|      6 |     11 |      1 |     18
               |  33.33 |  61.11 |   5.56 |
               |  19.35 |  13.58 |   0.88 |
      ---------+--------+--------+--------+
      59.6-59.7|     15 |     15 |     16 |     46
               |  32.61 |  32.61 |  34.78 |
               |  48.39 |  18.52 |  14.16 |
      ---------+--------+--------+--------+
      59.7-59.8|     10 |     43 |     57 |    110
               |   9.09 |  39.09 |  51.82 |
               |  32.26 |  53.09 |  50.44 |
      ---------+--------+--------+--------+
      59.8-60.0|      0 |     12 |     39 |     51
               |   0.00 |  23.53 |  76.47 |
               |   0.00 |  14.81 |  34.51 |
      ---------+--------+--------+--------+
      Total          31       81      113      225

                   Somers' D C|R
          ----------------------------------
          Somers' D C|R              0.3567
          ASE                        0.0462
          95% Lower Conf Limit       0.2662
          95% Upper Conf Limit       0.4473

            Test of H0: Somers' D C|R = 0

          ASE under H0               0.0489
          Z                          7.2957
          One-sided Pr >  Z          <.0001
          Two-sided Pr > |Z|         <.0001
```

Table 49. Two-way frequency analysis for ocean-tagged Sproat-bound Sockeye migration rate categories (km/d, in columns) versus Sproat water level categories (m, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.



```
-------- Tagging Location=Ocean Stock=SPR ----------

                The FREQ Procedure

       Table of Ppt_Level_Cat by FishSpeedCat

   Ppt_Level_Cat(Precipitation Level)
             FishSpeedCat(Mig Rate Category (km/d))

   Frequency|
   Row Pct  |
   Col Pct  |0-2     |2-4     |4+      |  Total
   ---------+--------+--------+--------+
   0.None   |     30 |     64 |     65 |    159
            |  18.87 |  40.25 |  40.88 |
            |  96.77 |  79.01 |  57.52 |
   ---------+--------+--------+--------+
   1.Low    |      1 |      5 |     15 |     21
            |   4.76 |  23.81 |  71.43 |
            |   3.23 |   6.17 |  13.27 |
   ---------+--------+--------+--------+
   2.High   |      0 |     12 |     33 |     45
            |   0.00 |  26.67 |  73.33 |
            |   0.00 |  14.81 |  29.20 |
   ---------+--------+--------+--------+
   Total          31       81      113      225

                 Somers' D C|R
       ----------------------------------
       Somers' D C|R               0.3338
       ASE                         0.0583
       95% Lower Conf Limit        0.2194
       95% Upper Conf Limit        0.4481

         Test of H0: Somers' D C|R = 0

       ASE under H0                0.0616
       Z                           5.4169
       One-sided Pr >  Z           <.0001
       Two-sided Pr > |Z|          <.0001
```

Table 50. Two-way frequency analysis for ocean-tagged Sproat-bound Sockeye migration rate categories (km/d, in columns) versus precipitation level categories (zero, <1 mm/d and >1 mm/d; in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
--------- Tagging Location=Ocean Stock=SPR ----------

                   The FREQ Procedure

         Table of Baro_Level_Cat by FishSpeedCat

      Baro_Level_Cat(Baro Pressure Level)
                   FishSpeedCat(Mig Rate Category (km/d))

      Frequency|
      Row Pct  |
      Col Pct  |0-2     |2-4     |4+      |  Total
      ---------+--------+--------+--------+
      0.83-0.85|      2 |      9 |      4 |     15
               |  13.33 |  60.00 |  26.67 |
               |   6.45 |  11.11 |   3.54 |
      ---------+--------+--------+--------+
      0.85-0.88|     20 |     47 |     62 |    129
               |  15.50 |  36.43 |  48.06 |
               |  64.52 |  58.02 |  54.87 |
      ---------+--------+--------+--------+
      0.88-0.90|      9 |     25 |     47 |     81
               |  11.11 |  30.86 |  58.02 |
               |  29.03 |  30.86 |  41.59 |
      ---------+--------+--------+--------+
      Total          31       81      113      225

                  Somers' D C|R
        ----------------------------------
        Somers' D C|R              0.1321
        ASE                        0.0627
        95% Lower Conf Limit       0.0092
        95% Upper Conf Limit       0.2550

          Test of H0: Somers' D C|R = 0

        ASE under H0               0.0632
        Z                          2.0903
        One-sided Pr >  Z          0.0183
        Two-sided Pr > |Z|         0.0366
```

Table 51. Two-way frequency analysis for ocean-tagged Sproat-bound Sockeye migration rate categories (km/d, in columns) versus barometric pressure level categories (mm, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
-------- Tagging Location=River Stock=GCL ----------

                The FREQ Procedure

     Table of STP_Water_Level_Cat by FishSpeedCat

   STP_Water_Level_Cat(Stamp Water Level)
             FishSpeedCat(Mig Rate Category (km/d))

   Frequency|
   Row Pct  |
   Col Pct  |0-2     |2-4     |4+      |  Total
   ---------+--------+--------+--------+
   0.74-0.81|      2 |     20 |      5 |     27
            |   7.41 |  74.07 |  18.52 |
            |   8.70 |  24.39 |  29.41 |
   ---------+--------+--------+--------+
   0.81-0.90|     10 |     17 |      8 |     35
            |  28.57 |  48.57 |  22.86 |
            |  43.48 |  20.73 |  47.06 |
   ---------+--------+--------+--------+
   0.95-1.20|     11 |     45 |      4 |     60
            |  18.33 |  75.00 |   6.67 |
            |  47.83 |  54.88 |  23.53 |
   ---------+--------+--------+--------+
   Total          23       82       17      122

               Somers' D C¦R
        --------------------------------
        Somers' D C¦R            -0.1123
        ASE                       0.0647
        95% Lower Conf Limit     -0.2392
        95% Upper Conf Limit      0.0145

        Test of H0: Somers' D C¦R = 0

        ASE under H0              0.0650
        Z                        -1.7288
        One-sided Pr <  Z         0.0419
        Two-sided Pr > ¦Z¦        0.0838
```

Table 52. Two-way frequency analysis for river-tagged GCL-bound Sockeye migration rate categories (km/d, in columns) versus Stamp water level categories (m, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
------- Tagging Location=River Stock=GCL ----------

               The FREQ Procedure

       Table of SPR_Temp_Cat by FishSpeedCat

  SPR_Temp_Cat(Sproat Temp C (3d Avg))
           FishSpeedCat(Mig Rate Category (km/d))

  Frequency|
  Row Pct  |
  Col Pct  |0-2     |2-4     |4+      |  Total
  ---------+--------+--------+--------+
  18-19    |      1 |      9 |      0 |     10
           |  10.00 |  90.00 |   0.00 |
           |   4.35 |  10.98 |   0.00 |
  ---------+--------+--------+--------+
  19-20    |      3 |      3 |      7 |     13
           |  23.08 |  23.08 |  53.85 |
           |  13.04 |   3.66 |  41.18 |
  ---------+--------+--------+--------+
  20-21    |      4 |     45 |      3 |     52
           |   7.69 |  86.54 |   5.77 |
           |  17.39 |  54.88 |  17.65 |
  ---------+--------+--------+--------+
  >21      |     15 |     25 |      7 |     47
           |  31.91 |  53.19 |  14.89 |
           |  65.22 |  30.49 |  41.18 |
  ---------+--------+--------+--------+
  Total          23       82       17      122

              Somers' D C|R
     ------------------------------
     Somers' D C|R          -0.1478
     ASE                     0.0813
     95% Lower Conf Limit   -0.3071
     95% Upper Conf Limit    0.0115

       Test of H0: Somers' D C|R = 0

     ASE under H0            0.0812
     Z                      -1.8192
     One-sided Pr <  Z       0.0344
     Two-sided Pr > |Z|      0.0689
```

Table 53. Two-way frequency analysis for river-tagged GCL-bound Sockeye migration rate categories (km/d, in columns) versus Sproat water temperature categories (°C, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
--------- Tagging Location=River Stock=SPR ----------

                 The FREQ Procedure

      Table of STP_Water_Level_Cat by FishSpeedCat

     STP_Water_Level_Cat(Stamp Water Level)
                FishSpeedCat(Mig Rate Category (km/d))

     Frequency|
     Row Pct  |
     Col Pct  |0-2     |2-4     |4+      |  Total
     ---------+--------+--------+--------+
     0.74-0.81|     32 |     14 |      2 |     48
              |  66.67 |  29.17 |   4.17 |
              |  12.70 |  20.59 | 100.00 |
     ---------+--------+--------+--------+
     0.81-0.90|     78 |     33 |      0 |    111
              |  70.27 |  29.73 |   0.00 |
              |  30.95 |  48.53 |   0.00 |
     ---------+--------+--------+--------+
     0.95-1.20|    142 |     21 |      0 |    163
              |  87.12 |  12.88 |   0.00 |
              |  56.35 |  30.88 |   0.00 |
     ---------+--------+--------+--------+
     Total         252       68        2      322

                   Somers' D C|R
          ----------------------------------
          Somers' D C|R              -0.1584
          ASE                         0.0407
          95% Lower Conf Limit       -0.2382
          95% Upper Conf Limit       -0.0786

            Test of H0: Somers' D C|R = 0

          ASE under H0                0.0407
          Z                          -3.8891
          One-sided Pr <  Z           <.0001
          Two-sided Pr > |Z|          0.0001
```

Table 54. Two-way frequency analysis for river-tagged Sproat-bound Sockeye migration rate categories (km/d, in columns) versus Stamp water level categories (m, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
-------- Tagging Location=River Stock=SPR ----------

                 The FREQ Procedure

        Table of STP_Temp_Cat by FishSpeedCat

    STP_Temp_Cat(Stamp Temp C (3d Avg))
             FishSpeedCat(Mig Rate Category (km/d))

    Frequency|
    Row Pct  |
    Col Pct  |0-2     |2-4     |4+      |  Total
    ---------+--------+--------+--------+
    16-17    |     39 |     12 |      0 |     51
             |  76.47 |  23.53 |   0.00 |
             |  15.48 |  17.65 |   0.00 |
    ---------+--------+--------+--------+
    17-18    |     88 |     41 |      0 |    129
             |  68.22 |  31.78 |   0.00 |
             |  34.92 |  60.29 |   0.00 |
    ---------+--------+--------+--------+
    18-19    |     58 |      1 |      0 |     59
             |  98.31 |   1.69 |   0.00 |
             |  23.02 |   1.47 |   0.00 |
    ---------+--------+--------+--------+
    19-20    |     54 |     14 |      2 |     70
             |  77.14 |  20.00 |   2.86 |
             |  21.43 |  20.59 | 100.00 |
    ---------+--------+--------+--------+
    20-21    |     10 |      0 |      0 |     10
             | 100.00 |   0.00 |   0.00 |
             |   3.97 |   0.00 |   0.00 |
    ---------+--------+--------+--------+
    >21      |      3 |      0 |      0 |      3
             | 100.00 |   0.00 |   0.00 |
             |   1.19 |   0.00 |   0.00 |
    ---------+--------+--------+--------+
    Total         252       68        2      322

                Somers' D C|R
       ------------------------------------
       Somers' D C|R               -0.0833
       ASE                          0.0339
       95% Lower Conf Limit        -0.1497
       95% Upper Conf Limit        -0.0169

        Test of H0: Somers' D C|R = 0

       ASE under H0                 0.0339
       Z                           -2.4590
       One-sided Pr <  Z            0.0070
       Two-sided Pr > |Z|           0.0139
```

Table 55. Two-way frequency analysis for river-tagged Sproat-bound Sockeye migration rate categories (km/d, in columns) versus Stamp water temperature categories (°C, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
-------- Tagging Location=River Stock=SPR ----------

                The FREQ Procedure

       Table of SPR_Temp_Cat by FishSpeedCat

     SPR_Temp_Cat(Sproat Temp C (3d Avg))
               FishSpeedCat(Mig Rate Category (km/d))

     Frequency|
     Row Pct  |
     Col Pct  |0-2     |2-4     |4+      |  Total
     ---------+--------+--------+--------+
     18-19    |     35 |      7 |      0 |     42
              |  83.33 |  16.67 |   0.00 |
              |  13.89 |  10.29 |   0.00 |
     ---------+--------+--------+--------+
     19-20    |      5 |     25 |      0 |     30
              |  16.67 |  83.33 |   0.00 |
              |   1.98 |  36.76 |   0.00 |
     ---------+--------+--------+--------+
     20-21    |    126 |     21 |      0 |    147
              |  85.71 |  14.29 |   0.00 |
              |  50.00 |  30.88 |   0.00 |
     ---------+--------+--------+--------+
     >21      |     86 |     15 |      2 |    103
              |  83.50 |  14.56 |   1.94 |
              |  34.13 |  22.06 | 100.00 |
     ---------+--------+--------+--------+
     Total         252       68        2      322

                  Somers' D C|R
          ------------------------------------
          Somers' D C|R                -0.1158
          ASE                           0.0392
          95% Lower Conf Limit         -0.1926
          95% Upper Conf Limit         -0.0389

            Test of H0: Somers' D C|R = 0

          ASE under H0                  0.0396
          Z                            -2.9231
          One-sided Pr <  Z             0.0017
          Two-sided Pr > |Z|            0.0035
```

Table 56. Two-way frequency analysis for river-tagged Sproat-bound Sockeye migration rate categories (km/d, in columns) versus Sproat water temperature categories (°C, in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
------- Tagging Location=River Stock=SPR ----------

                The FREQ Procedure

      Table of Ppt_Level_Cat by FishSpeedCat

   Ppt_Level_Cat(Precipitation Level)
             FishSpeedCat(Mig Rate Category (km/d))

   Frequency|
   Row Pct  |
   Col Pct  |0-2     |2-4     |4+      |  Total
   ---------+--------+--------+--------+
   0.None   |    184 |     42 |      0 |    226
            |  81.42 |  18.58 |   0.00 |
            |  73.02 |  61.76 |   0.00 |
   ---------+--------+--------+--------+
   1.Low    |     14 |      5 |      0 |     19
            |  73.68 |  26.32 |   0.00 |
            |   5.56 |   7.35 |   0.00 |
   ---------+--------+--------+--------+
   2.High   |     54 |     21 |      2 |     77
            |  70.13 |  27.27 |   2.60 |
            |  21.43 |  30.88 | 100.00 |
   ---------+--------+--------+--------+
   Total         252       68        2      322

                 Somers' D C|R
        ------------------------------------
        Somers' D C|R               0.1054
        ASE                         0.0510
        95% Lower Conf Limit        0.0055
        95% Upper Conf Limit        0.2054

          Test of H0: Somers' D C|R = 0

        ASE under H0                0.0512
        Z                           2.0581
        One-sided Pr >  Z           0.0198
        Two-sided Pr > |Z|          0.0396
```

Table 57. Two-way frequency analysis for river-tagged Sproat-bound Sockeye migration rate categories (km/d, in columns) versus precipitation level categories (zero, <1 mm/d and >1 mm/d; in rows). Cells contain frequency count, row percentage, and column percentage for each combination. Somers' D statistic and Z-score indicate degree of association between columns (dependent variate) on rows.

```
   Table 1 of PMD_Temp_Cat by FishSpeedCat
Controlling for STP_Water_Level_Basic=1.Low

PMD_Temp_Cat(Somass Temp C (3d Avg))
           FishSpeedCat(Mig Rate Category (km/d))

Frequency|
Row Pct  |
Col Pct  |0-2     |2-4     |4+      |  Total
---------+--------+--------+--------+
16-17    |      0 |      8 |      7 |     15
         |   0.00 |  53.33 |  46.67 |
         |   0.00 |  16.67 |  19.44 |
---------+--------+--------+--------+
17-18    |      0 |      3 |      4 |      7
         |   0.00 |  42.86 |  57.14 |
         |   0.00 |   6.25 |  11.11 |
---------+--------+--------+--------+
18-19    |      4 |     19 |     23 |     46
         |   8.70 |  41.30 |  50.00 |
         |  26.67 |  39.58 |  63.89 |
---------+--------+--------+--------+
19-20    |     10 |     16 |      2 |     28
         |  35.71 |  57.14 |   7.14 |
         |  66.67 |  33.33 |   5.56 |
---------+--------+--------+--------+
20-21    |      1 |      2 |      0 |      3
         |  33.33 |  66.67 |   0.00 |
         |   6.67 |   4.17 |   0.00 |
---------+--------+--------+--------+
Total          15       48       36       99
```

```
   Table 2 of PMD_Temp_Cat by FishSpeedCat
Controlling for STP_Water_Level_Basic=2.High

PMD_Temp_Cat(Somass Temp C (3d Avg))
           FishSpeedCat(Mig Rate Category (km/d))

Frequency|
Row Pct  |
Col Pct  |0-2     |2-4     |4+      |  Total
---------+--------+--------+--------+
16-17    |      0 |      2 |      2 |      4
         |   0.00 |  50.00 |  50.00 |
         |   0.00 |  11.11 |  16.67 |
---------+--------+--------+--------+
17-18    |      1 |      7 |      4 |     12
         |   8.33 |  58.33 |  33.33 |
         |  50.00 |  38.89 |  33.33 |
---------+--------+--------+--------+
18-19    |      1 |      9 |      6 |     16
         |   6.25 |  56.25 |  37.50 |
         |  50.00 |  50.00 |  50.00 |
---------+--------+--------+--------+
19-20    |      0 |      0 |      0 |      0
         |      . |      . |      . |
         |   0.00 |   0.00 |   0.00 |
---------+--------+--------+--------+
20-21    |      0 |      0 |      0 |      0
         |      . |      . |      . |
         |   0.00 |   0.00 |   0.00 |
---------+--------+--------+--------+
Total           2       18       12       32
```

```
     Summary Statistics for PMD_Temp_Cat by FishSpeedCat
           Controlling for STP_Water_Level_Basic

  Cochran-Mantel-Haenszel Statistics (Based on Table Scores)

Statistic    Alternative Hypothesis    DF       Value      Prob
---------------------------------------------------------------
    1        Nonzero Correlation        1     14.0600    0.0002
    2        Row Mean Scores Differ     4     24.2168    <.0001
    3        General Association        8     25.0495    0.0015

                   Total Sample Size = 131
```

Table 58. Stratified three-way frequency analysis for ocean-tagged GCL-bound Sockeye migration rate categories (km/d, in columns) versus Somass water temperature categories (°C; in rows), for Stamp River water level strata ("Low": <1m, left; "High": >1m, right). Cells contain frequency count, row percentage, and column percentage for each combination. Cochran-Mantel-Haenszel statistics indicate high degree of association between columns and rows within strata.

```
Table 1 of PMD_Temp_Cat by FishSpeedCat
Controlling for Baro_Level_Basic=1.Low

PMD_Temp_Cat(Somass Temp C (3d Avg))
          FishSpeedCat(Mig Rate Category (km/d))

Frequency|
Row Pct  |
Col Pct  |0-2     |2-4     |4+      |  Total
---------+--------+--------+--------+
16-17    |      0 |      1 |      1 |      2
         |   0.00 |  50.00 |  50.00 |
         |   0.00 |  25.00 | 100.00 |
---------+--------+--------+--------+
17-18    |      0 |      0 |      0 |      0
         |      . |      . |      . |
         |   0.00 |   0.00 |   0.00 |
---------+--------+--------+--------+
18-19    |      0 |      0 |      0 |      0
         |      . |      . |      . |
         |   0.00 |   0.00 |   0.00 |
---------+--------+--------+--------+
19-20    |      5 |      3 |      0 |      8
         |  62.50 |  37.50 |   0.00 |
         | 100.00 |  75.00 |   0.00 |
---------+--------+--------+--------+
20-21    |      0 |      0 |      0 |      0
         |      . |      . |      . |
         |   0.00 |   0.00 |   0.00 |
---------+--------+--------+--------+
Total           5        4        1       10
```

```
Table 2 of PMD_Temp_Cat by FishSpeedCat
Controlling for Baro_Level_Basic=2.High

PMD_Temp_Cat(Somass Temp C (3d Avg))
          FishSpeedCat(Mig Rate Category (km/d))

Frequency|
Row Pct  |
Col Pct  |0-2     |2-4     |4+      |  Total
---------+--------+--------+--------+
16-17    |      0 |      9 |      8 |     17
         |   0.00 |  52.94 |  47.06 |
         |   0.00 |  14.52 |  17.02 |
---------+--------+--------+--------+
17-18    |      1 |     10 |      8 |     19
         |   5.26 |  52.63 |  42.11 |
         |   8.33 |  16.13 |  17.02 |
---------+--------+--------+--------+
18-19    |      5 |     28 |     29 |     62
         |   8.06 |  45.16 |  46.77 |
         |  41.67 |  45.16 |  61.70 |
---------+--------+--------+--------+
19-20    |      5 |     13 |      2 |     20
         |  25.00 |  65.00 |  10.00 |
         |  41.67 |  20.97 |   4.26 |
---------+--------+--------+--------+
20-21    |      1 |      2 |      0 |      3
         |  33.33 |  66.67 |   0.00 |
         |   8.33 |   3.23 |   0.00 |
---------+--------+--------+--------+
Total          12       62       47      121
```

```
          Summary Statistics for PMD_Temp_Cat by FishSpeedCat
                  Controlling for Baro_Level_Basic

       Cochran-Mantel-Haenszel Statistics (Based on Table Scores)

    Statistic    Alternative Hypothesis    DF       Value      Prob
    ---------------------------------------------------------------
        1        Nonzero Correlation        1     12.3429    0.0004
        2        Row Mean Scores Differ     4     19.2023    0.0007
        3        General Association        8     20.1070    0.0099

                       Total Sample Size = 131
```

Table 59. Stratified three-way frequency analysis for ocean-tagged GCL-bound Sockeye migration rate categories (km/d, in columns) versus Somass water temperature categories (°C; in rows), for barometric pressure level strata ("Low": <0.84 mbar, left; "High": >0.84 mbar, right). Cells contain frequency count, row percentage, and column percentage for each combination. Cochran-Mantel-Haenszel statistics indicate high degree of association between columns and rows within strata.

```
   Table 1 of PMD_Temp_Cat by FishSpeedCat
    Controlling for Ppt_Level_Basic=0.None

PMD_Temp_Cat(Somass Temp C (3d Avg))
          FishSpeedCat(Mig Rate Category (km/d))

Frequency|
Row Pct  |
Col Pct  |0-2     |2-4     |4+      |  Total
---------+--------+--------+--------+
16-17    |      0 |      1 |      1 |      2
         |   0.00 |  50.00 |  50.00 |
         |   0.00 |   1.89 |   2.78 |
---------+--------+--------+--------+
17-18    |      1 |      7 |      4 |     12
         |   8.33 |  58.33 |  33.33 |
         |   5.88 |  13.21 |  11.11 |
---------+--------+--------+--------+
18-19    |      5 |     28 |     29 |     62
         |   8.06 |  45.16 |  46.77 |
         |  29.41 |  52.83 |  80.56 |
---------+--------+--------+--------+
19-20    |     10 |     15 |      2 |     27
         |  37.04 |  55.56 |   7.41 |
         |  58.82 |  28.30 |   5.56 |
---------+--------+--------+--------+
20-21    |      1 |      2 |      0 |      3
         |  33.33 |  66.67 |   0.00 |
         |   5.88 |   3.77 |   0.00 |
---------+--------+--------+--------+
Total          17       53       36      106
```

```
   Table 2 of PMD_Temp_Cat by FishSpeedCat
     Controlling for Ppt_Level_Basic=Rain

PMD_Temp_Cat(Somass Temp C (3d Avg))
          FishSpeedCat(Mig Rate Category (km/d))

Frequency|
Row Pct  |
Col Pct  |0-2     |2-4     |4+      |  Total
---------+--------+--------+--------+
16-17    |      0 |      9 |      8 |     17
         |   0.00 |  52.94 |  47.06 |
         |      . |  69.23 |  66.67 |
---------+--------+--------+--------+
17-18    |      0 |      3 |      4 |      7
         |   0.00 |  42.86 |  57.14 |
         |      . |  23.08 |  33.33 |
---------+--------+--------+--------+
18-19    |      0 |      0 |      0 |      0
         |      . |      . |      . |
         |      . |   0.00 |   0.00 |
---------+--------+--------+--------+
19-20    |      0 |      1 |      0 |      1
         |   0.00 | 100.00 |   0.00 |
         |      . |   7.69 |   0.00 |
---------+--------+--------+--------+
20-21    |      0 |      0 |      0 |      0
         |      . |      . |      . |
         |      . |   0.00 |   0.00 |
---------+--------+--------+--------+
Total           0       13       12       25
```

```
            Summary Statistics for PMD_Temp_Cat by FishSpeedCat
                    Controlling for Ppt_Level_Basic

         Cochran-Mantel-Haenszel Statistics (Based on Table Scores)

    Statistic    Alternative Hypothesis    DF       Value      Prob
    ---------------------------------------------------------------
        1        Nonzero Correlation        1     12.2081    0.0005
        2        Row Mean Scores Differ     4     21.4048    0.0003
        3        General Association        8     22.0607    0.0048
```

Table 60. Stratified three-way frequency analysis for ocean-tagged GCL-bound Sockeye migration rate categories (km/d, in columns) versus Somass water temperature categories (°C; in rows), for precipitation level strata ("None": <0.001 mm/d, left; "Rain": > 0.001 mm/d, right). Cells contain frequency count, row percentage, and column percentage for each combination. Cochran-Mantel-Haenszel statistics indicate high degree of association between columns and rows within strata.

```
   Table 1 of SPR_Temp_Cat by FishSpeedCat
Controlling for SPR_Water_Level_Basic=1.Low

SPR_Temp_Cat(Sproat Temp C (3d Avg))
          FishSpeedCat(Mig Rate Category (km/d))

Frequency|
Row Pct  |
Col Pct  |0-2     |2-4     |4+      |  Total
---------+--------+--------+--------+
18-19    |      0 |      0 |      0 |      0
         |      . |      . |      . |
         |   0.00 |   0.00 |   0.00 |
---------+--------+--------+--------+
19-20    |      2 |      7 |     19 |     28
         |   7.14 |  25.00 |  67.86 |
         |   6.45 |  10.14 |  25.68 |
---------+--------+--------+--------+
20-21    |      6 |     18 |     25 |     49
         |  12.24 |  36.73 |  51.02 |
         |  19.35 |  26.09 |  33.78 |
---------+--------+--------+--------+
>21      |     23 |     44 |     30 |     97
         |  23.71 |  45.36 |  30.93 |
         |  74.19 |  63.77 |  40.54 |
---------+--------+--------+--------+
Total          31       69       74      174

   Table 2 of SPR_Temp_Cat by FishSpeedCat
Controlling for SPR_Water_Level_Basic=2.High

SPR_Temp_Cat(Sproat Temp C (3d Avg))
          FishSpeedCat(Mig Rate Category (km/d)

Frequency|
Row Pct  |
Col Pct  |0-2     |2-4     |4+      |  Total
---------+--------+--------+--------+
18-19    |      0 |     12 |     39 |     51
         |   0.00 |  23.53 |  76.47 |
         |      . | 100.00 | 100.00 |
---------+--------+--------+--------+
19-20    |      0 |      0 |      0 |      0
         |      . |      . |      . |
         |      . |   0.00 |   0.00 |
---------+--------+--------+--------+
20-21    |      0 |      0 |      0 |      0
         |      . |      . |      . |
         |      . |   0.00 |   0.00 |
---------+--------+--------+--------+
>21      |      0 |      0 |      0 |      0
         |      . |      . |      . |
         |      . |   0.00 |   0.00 |
---------+--------+--------+--------+
Total           0       12       39       51

      Summary Statistics for SPR_Temp_Cat by FishSpeedCat
             Controlling for SPR_Water_Level_Basic

   Cochran-Mantel-Haenszel Statistics (Based on Table Scores)

 Statistic    Alternative Hypothesis    DF       Value      Prob
 ---------------------------------------------------------------
     1        Nonzero Correlation        1     13.7394    0.0002
     2        Row Mean Scores Differ     3           .         .
     3        General Association        6           .         .

   At least 1 statistic not computed--singular covariance matrix.

                     Total Sample Size = 225
```

Table 61. Stratified three-way frequency analysis for ocean-tagged Sproat-bound Sockeye migration rate categories (km/d, in columns) versus Sproat water temperature categories (°C; in rows), for Sproat Lake water level strata ("Low": <59.8m, left; "High": >59.8m, right). Cells contain frequency count, row percentage, and column percentage for each combination. Cochran-Mantel-Haenszel statistics indicate high degree of association between columns and rows within strata.

```
     Table 1 of SPR_Temp_Cat by FishSpeedCat
      Controlling for Baro_Level_Basic=1.Low

SPR_Temp_Cat(Sproat Temp C (3d Avg))
             FishSpeedCat(Mig Rate Category (km/d))

Frequency|
Row Pct  |
Col Pct  |0-2     |2-4     |4+      |  Total
---------+--------+--------+--------+
18-19    |      0 |      0 |      4 |      4
         |   0.00 |   0.00 | 100.00 |
         |   0.00 |   0.00 | 100.00 |
---------+--------+--------+--------+
19-20    |      0 |      0 |      0 |      0
         |      . |      . |      . |
         |   0.00 |   0.00 |   0.00 |
---------+--------+--------+--------+
20-21    |      0 |      0 |      0 |      0
         |      . |      . |      . |
         |   0.00 |   0.00 |   0.00 |
---------+--------+--------+--------+
>21      |      2 |      9 |      0 |     11
         |  18.18 |  81.82 |   0.00 |
         | 100.00 | 100.00 |   0.00 |
---------+--------+--------+--------+
Total           2        9        4       15
```

```
     Table 2 of SPR_Temp_Cat by FishSpeedCat
     Controlling for Baro_Level_Basic=2.High

SPR_Temp_Cat(Sproat Temp C (3d Avg))
             FishSpeedCat(Mig Rate Category (km/d))

Frequency|
Row Pct  |
Col Pct  |0-2     |2-4     |4+      |  Total
---------+--------+--------+--------+
18-19    |      0 |     12 |     35 |     47
         |   0.00 |  25.53 |  74.47 |
         |   0.00 |  16.67 |  32.11 |
---------+--------+--------+--------+
19-20    |      2 |      7 |     19 |     28
         |   7.14 |  25.00 |  67.86 |
         |   6.90 |   9.72 |  17.43 |
---------+--------+--------+--------+
20-21    |      6 |     18 |     25 |     49
         |  12.24 |  36.73 |  51.02 |
         |  20.69 |  25.00 |  22.94 |
---------+--------+--------+--------+
>21      |     21 |     35 |     30 |     86
         |  24.42 |  40.70 |  34.88 |
         |  72.41 |  48.61 |  27.52 |
---------+--------+--------+--------+
Total          29       72      109      210
```

```
          Summary Statistics for SPR_Temp_Cat by FishSpeedCat
                  Controlling for Baro_Level_Basic

     Cochran-Mantel-Haenszel Statistics (Based on Table Scores)

   Statistic    Alternative Hypothesis    DF       Value      Prob
   ---------------------------------------------------------------
       1        Nonzero Correlation        1     34.2194    <.0001
       2        Row Mean Scores Differ     3     34.6342    <.0001
       3        General Association        6     35.2251    <.0001

                     Total Sample Size = 225
```

Table 62. Stratified three-way frequency analysis for ocean-tagged Sproat-bound Sockeye migration rate categories (km/d, in columns) versus Sproat water temperature categories (°C; in rows), for barometric pressure level strata ("Low": <0.84 mbar, left; "High": >0.84 mbar, right). Cells contain frequency count, row percentage, and column percentage for each combination. Cochran-Mantel-Haenszel statistics indicate high degree of association between columns and rows within strata.

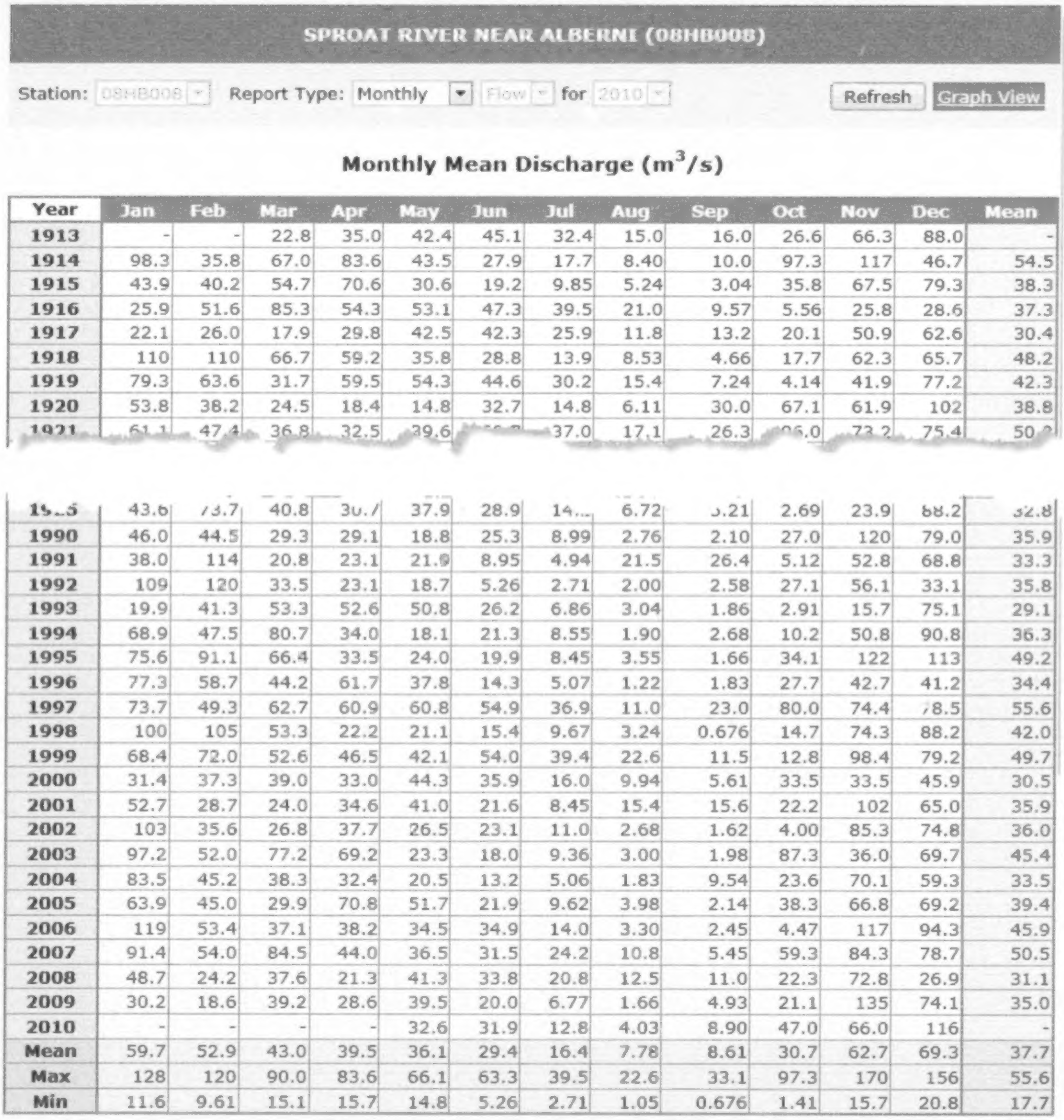
```
   Table 1 of SPR_Temp_Cat by FishSpeedCat
    Controlling for Ppt_Level_Basic=None

SPR_Temp_Cat(Sproat Temp C (3d Avg))
          FishSpeedCat(Mig Rate Category (km/d))

Frequency|
Row Pct  |
Col Pct  |0-2     |2-4     |4+      |  Total
---------+--------+--------+--------+
18-19    |      0 |      0 |      3 |      3
         |   0.00 |   0.00 | 100.00 |
         |   0.00 |   0.00 |   4.62 |
---------+--------+--------+--------+
19-20    |      1 |      2 |      7 |     10
         |  10.00 |  20.00 |  70.00 |
         |   3.33 |   3.13 |  10.77 |
---------+--------+--------+--------+
20-21    |      6 |     18 |     25 |     49
         |  12.24 |  36.73 |  51.02 |
         |  20.00 |  28.13 |  38.46 |
---------+--------+--------+--------+
>21      |     23 |     44 |     30 |     97
         |  23.71 |  45.36 |  30.93 |
         |  76.67 |  68.75 |  46.15 |
---------+--------+--------+--------+
Total          30       64       65      159
```

```
   Table 2 of SPR_Temp_Cat by FishSpeedCat
    Controlling for Ppt_Level_Basic=Rain

SPR_Temp_Cat(Sproat Temp C (3d Avg))
          FishSpeedCat(Mig Rate Category (km/d))

Frequency|
Row Pct  |
Col Pct  |0-2     |2-4     |4+      |  Total
---------+--------+--------+--------+
18-19    |      0 |     12 |     36 |     48
         |   0.00 |  25.00 |  75.00 |
         |   0.00 |  70.59 |  75.00 |
---------+--------+--------+--------+
19-20    |      1 |      5 |     12 |     18
         |   5.56 |  27.78 |  66.67 |
         | 100.00 |  29.41 |  25.00 |
---------+--------+--------+--------+
20-21    |      0 |      0 |      0 |      0
         |      . |      . |      . |
         |   0.00 |   0.00 |   0.00 |
---------+--------+--------+--------+
>21      |      0 |      0 |      0 |      0
         |      . |      . |      . |
         |   0.00 |   0.00 |   0.00 |
---------+--------+--------+--------+
Total           1       17       48       66
```

```
       Summary Statistics for SPR_Temp_Cat by FishSpeedCat
                Controlling for Ppt_Level_Basic

    Cochran-Mantel-Haenszel Statistics (Based on Table Scores)

  Statistic    Alternative Hypothesis    DF       Value      Prob
  ---------------------------------------------------------------
      1        Nonzero Correlation        1     13.1853    0.0003
      2        Row Mean Scores Differ     3     13.2883    0.0041
      3        General Association        6     15.7624    0.0151

                     Total Sample Size = 225
```

Table 63. Stratified three-way frequency analysis for ocean-tagged Sproat-bound Sockeye migration rate categories (km/d, in columns) versus Sproat water temperature categories (°C; in rows), for precipitation level strata ("None": <0.001 mm/d, left; "Rain": > 0.001 mm/d, right). Cells contain frequency count, row percentage, and column percentage for each combination. Cochran-Mantel-Haenszel statistics indicate high degree of association between columns and rows within strata.

APPENDIX TABLES



SPROAT RIVER NEAR ALBERNI (08HB008)

Monthly Mean Discharge (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1913	-	-	22.8	35.0	42.4	45.1	32.4	15.0	16.0	26.6	66.3	88.0	-
1914	98.3	35.8	67.0	83.6	43.5	27.9	17.7	8.40	10.0	97.3	117	46.7	54.5
1915	43.9	40.2	54.7	70.6	30.6	19.2	9.85	5.24	3.04	35.8	67.5	79.3	38.3
1916	25.9	51.6	85.3	54.3	53.1	47.3	39.5	21.0	9.57	5.56	25.8	28.6	37.3
1917	22.1	26.0	17.9	29.8	42.5	42.3	25.9	11.8	13.2	20.1	50.9	62.6	30.4
1918	110	110	66.7	59.2	35.8	28.8	13.9	8.53	4.66	17.7	62.3	65.7	48.2
1919	79.3	63.6	31.7	59.5	54.3	44.6	30.2	15.4	7.24	4.14	41.9	77.2	42.3
1920	53.8	38.2	24.5	18.4	14.8	32.7	14.8	6.11	30.0	67.1	61.9	102	38.8
1921	61.1	47.4	36.8	32.5	39.6	[illegible]	37.0	17.1	26.3	[illegible]	73.2	75.4	[illegible]
[illegible]	43.6	73.7	40.8	30.7	37.9	28.9	[illegible]	6.72	[illegible]	2.69	23.9	68.2	32.8
1990	46.0	44.5	29.3	29.1	18.8	25.3	8.99	2.76	2.10	27.0	120	79.0	35.9
1991	38.0	114	20.8	23.1	21.9	8.95	4.94	21.5	26.4	5.12	52.8	68.8	33.3
1992	109	120	33.5	23.1	18.7	5.26	2.71	2.00	2.58	27.1	56.1	33.1	35.8
1993	19.9	41.3	53.3	52.6	50.8	26.2	6.86	3.04	1.86	2.91	15.7	75.1	29.1
1994	68.9	47.5	80.7	34.0	18.1	21.3	8.55	1.90	2.68	10.2	50.8	90.8	36.3
1995	75.6	91.1	66.4	33.5	24.0	19.9	8.45	3.55	1.66	34.1	122	113	49.2
1996	77.3	58.7	44.2	61.7	37.8	14.3	5.07	1.22	1.83	27.7	42.7	41.2	34.4
1997	73.7	49.3	62.7	60.9	60.8	54.9	36.9	11.0	23.0	80.0	74.4	78.5	55.6
1998	100	105	53.3	22.2	21.1	15.4	9.67	3.24	0.676	14.7	74.3	88.2	42.0
1999	68.4	72.0	52.6	46.5	42.1	54.0	39.4	22.6	11.5	12.8	98.4	79.2	49.7
2000	31.4	37.3	39.0	33.0	44.3	35.9	16.0	9.94	5.61	33.5	33.5	45.9	30.5
2001	52.7	28.7	24.0	34.6	41.0	21.6	8.45	15.4	15.6	22.2	102	65.0	35.9
2002	103	35.6	26.8	37.7	26.5	23.1	11.0	2.68	1.62	4.00	85.3	74.8	36.0
2003	97.2	52.0	77.2	69.2	23.3	18.0	9.36	3.00	1.98	87.3	36.0	69.7	45.4
2004	83.5	45.2	38.3	32.4	20.5	13.2	5.06	1.83	9.54	23.6	70.1	59.3	33.5
2005	63.9	45.0	29.9	70.8	51.7	21.9	9.62	3.98	2.14	38.3	66.8	69.2	39.4
2006	119	53.4	37.1	38.2	34.5	34.9	14.0	3.30	2.45	4.47	117	94.3	45.9
2007	91.4	54.0	84.5	44.0	36.5	31.5	24.2	10.8	5.45	59.3	84.3	78.7	50.5
2008	48.7	24.2	37.6	21.3	41.3	33.8	20.8	12.5	11.0	22.3	72.8	26.9	31.1
2009	30.2	18.6	39.2	28.6	39.5	20.0	6.77	1.66	4.93	21.1	135	74.1	35.0
2010	-	-	-	-	32.6	31.9	12.8	4.03	8.90	47.0	66.0	116	-
Mean	59.7	52.9	43.0	39.5	36.1	29.4	16.4	7.78	8.61	30.7	62.7	69.3	37.7
Max	128	120	90.0	83.6	66.1	63.3	39.5	22.6	33.1	97.3	170	156	55.6
Min	11.6	9.61	15.1	15.7	14.8	5.26	2.71	1.05	0.676	1.41	15.7	20.8	17.7

Appendix Table I. Sproat River near Alberni (WSC station 08HB008) mean monthly discharge (m3/s) 1913-2010, downloaded 12-Aug-2011 from WSC http://www.wsc.ec.gc.ca/applications/H2O/index-eng.cfm.

TagID	Partial Tag ID	Tagging Location	Tag Date	Tagging Time
0000_0000000174143038	43038			
0000_0000000174143138	43138			
0000_0000000174143828	43828			
0000_0000000174153048	53048			
0000_0000000174153339	53339			
0000_0000000174154234	54234			
0000_0000000174481993	81993			
0000_0000000174482024	82024			
0000_0000000174482054	82054			
0000_0000000174482173	82173			
0000_0000000174485236	85236			

Appendix Table II. Tag detection IDs without corresponding tag release information, possible transcription errors; omitted from analyses.

Week Ending	GCL Dam	Sproat Fishway
26-May		1.20%
2-Jun	0.00%	1.27%
9-Jun	0.00%	1.04%
16-Jun	0.00%	0.56%
23-Jun	0.01%	0.02%
30-Jun	0.00%	0.02%
7-Jul	0.00%	0.52%
14-Jul	0.00%	0.97%
21-Jul	0.00%	1.42%
28-Jul	0.00%	1.86%
4-Aug	0.00%	2.29%
11-Aug	0.00%	2.47%
18-Aug	0.00%	2.33%
25-Aug	0.00%	2.46%
1-Sep	0.00%	2.50%
8-Sep	0.00%	2.47%
15-Sep		2.43%
22-Sep		2.70%
29-Sep		2.51%
6-Oct		2.32%
13-Oct		0.51%
20-Oct		0.00%

Appendix Table III. Somass Sockeye weekly fishway bypass rates for Sockeye salmon at GCL and Sproat fishways (Source: Jeff Till, DFO, 30-Apr-11, pers. comm.).

Tag ID	Tagging Date	Tagging Location	Detection Date	Vessel	Location	Fishery Type
0000_0000000174143030	28-Jun-10	Argent 1	6-Jul-10	Taaska	Delta Pacific Seafoods	Seine
0000_0000000174142728	05-Jul-10	Argent 1	7-Jul-10	Truck	Hub City	gillnet
0000_0000000174144592	28-Jun-10	Argent 1	7-Jul-10	Santa Cruz	Aero Trading	Seine
0000_0000000174144071	05-Jul-10	Argent 1	7-Jul-10	Ocean Mistress	Aero Trading	gillnet
0000_0000000174143273	05-Jul-10	Argent 1	7-Jul-10	Ocean Mistress	Aero Trading	gillnet
0000_0000000174143154	05-Jul-10	Argent 1	7-Jul-10	Ocean Mistress	Aero Trading	gillnet
0000_0000000174144094	28-Jun-10	Argent 1	14-Jul-10	Nita Dawn	Bella Coola Fish	Seine
0000_0000000174143108	05-Jul-10	Argent 1	14-Jul-10	Nita Dawn	Bella Coola Fish	Seine
0000_0000000174144146	12-Jul-10	Argent 1	14-Jul-10	Ocean Mistress	Aero Trading	gillnet
0000_0000000174142735	12-Jul-10	Argent 1	14-Jul-10	Ocean Mistress	Aero Trading	gillnet
0000_0000000174143274	12-Jul-10	Argent 1	14-Jul-10	Ocean Mistress	Aero Trading	gillnet
0000_0000000174154136	06-Jul-10	PMD	14-Jul-10	Ocean Mistress	Aero Trading	gillnet
0000_0000000174143152	14-Jun-10	Argent 1	21-Jul-10	Santa Cruz	Aero Trading	Seine
0000_0000000174144354	05-Jul-10	Argent 1	21-Jul-10	Santa Cruz	Aero Trading	Seine
0000_0000000174143865	13-Jul-10	PMD	21-Jul-10	Unknown	Delta Pacific Seafoods	Seine
0000_0000000174142742	12-Jul-10	Argent 1	22-Jul-10	Unknown	Aero Trading	gillnet
0000_0000000174143232	14-Jun-10	Argent 1	22-Jul-10	Unknown	Aero Trading	gillnet
0000_0000000174481985	06-Jul-10	PMD	28-Jul-10	Western Voyager	Delta Pacific Seafoods	Seine
0000_0000000174143967	05-Jul-10	Argent 1	28-Jul-10	Ocean Destiny	Delta Pacific Seafoods	Seine
0000_0000000174143527	12-Jul-10	Argent 1	28-Jul-10	Ocean Destiny	Delta Pacific Seafoods	Seine
0000_0000000174143430	12-Jul-10	Argent 1	30-Jul-10	Ocean Mistress	Aero Trading	gillnet
0000_0000000174144077	21-Jun-10	Argent 1	30-Jul-10	Ocean Mistress	Aero Trading	gillnet
0000_0000000174143553	21-Jun-10	Argent 1	4-Aug-10	Viking Spirit	Bella Coola Fish	Seine
0000_0000000174154775	13-Jul-10	PMD	17-Jul-10		Clutesi Haven Marina	Sport
0000_0000000174143002	28-Jun-10	Argent 1	30-Jun-10		Numukamis Bay	FN
0000_0000000174144618	28-Jun-10	Argent 1	12-Jul-10		Silver Bridge	FN

Appendix Table IV. Recoveries of PIT tags from Sockeye salmon fisheries in 2010.